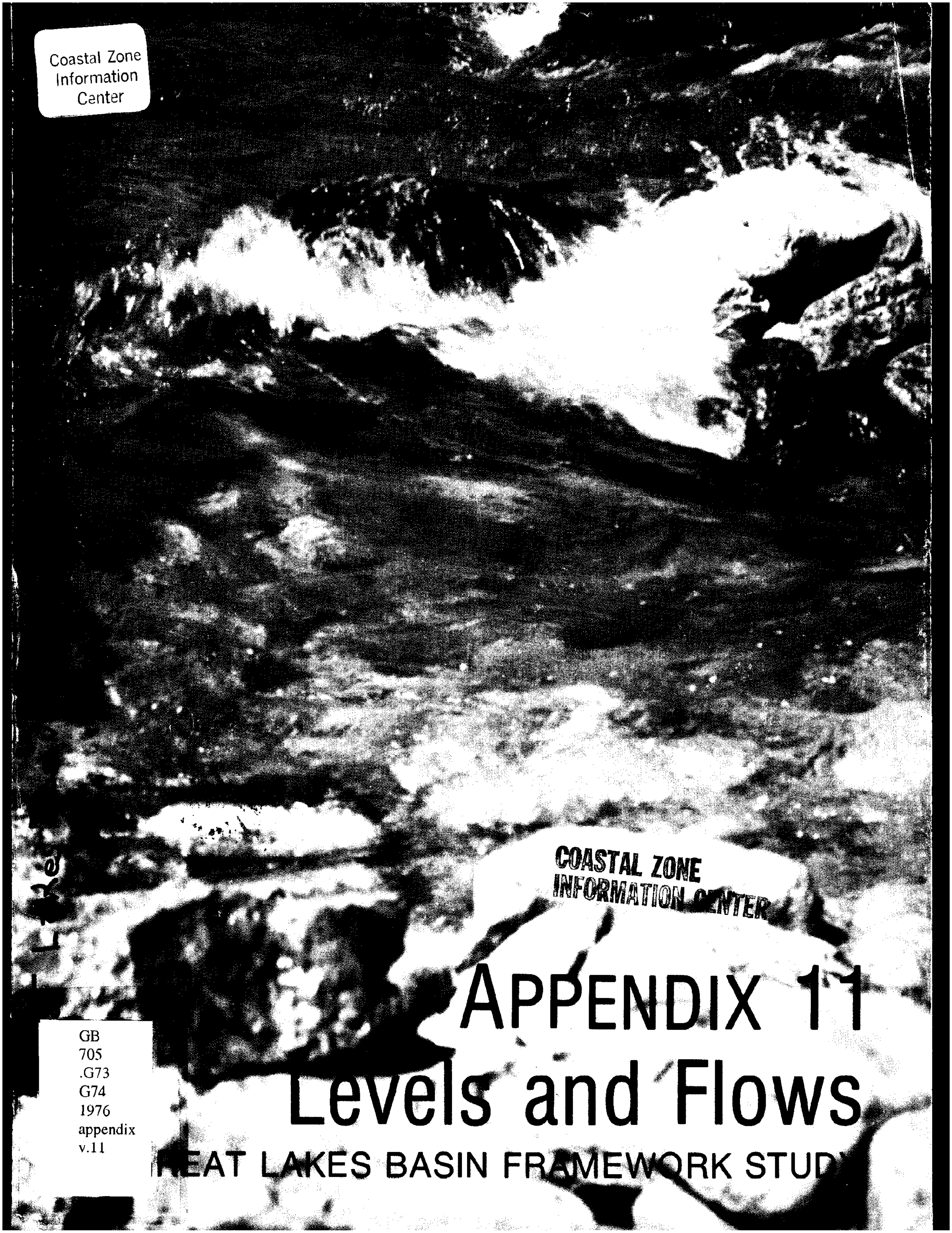

APPENDIX 11
Levels and Flows

REAT LAKES BASIN FRAMEWORK STUD

Great Lakes Basin Framework Study

APPENDIX 11

LEVELS AND FLOWS

GREAT LAKES BASIN COMMISSION

Prepared by Levels and Flows Work Group

Sponsored by U.S. Army Corps of Engineers, North Central Division

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Cover photo by Kristine Moore Meves.

This appendix to the *Report* of the *Great Lakes Basin Framework Study* was prepared at field level under the auspices of the Great Lakes Basin Commission to provide data for use in the conduct of the Study and preparation of the *Report*. The conclusions and recommendations herein are those of the group preparing the appendix and not necessarily those of the Basin Commission. The recommendations of the Great Lakes Basin Commission are included in the *Report*.

OUTLINE

SYNOPSIS

This appendix describes the factors which affect Great Lakes water levels and outflows. It discusses the physiography, hydraulics, and hydrology of the Great Lakes–St. Lawrence River system; diversions into, out of, and within the system; and lake regulation. In the discussion of regulation, the effects of lake level fluctuation on the various interests within the Basin are developed.

A regulation plan is a means of determining the flow out of a lake or a system of lakes for a given future period. It reroutes the historical supply of water through a lake to produce desired lake levels and outflows. There are two such plans in operation on the Great Lakes today. Both of these have been designed to satisfy certain criteria specified in Orders of Approval of the International Joint Commission.

Lake Superior has been regulated since 1921 by means of a gated dam across the St. Marys River at Sault Ste. Marie, Michigan. The objective of this control is to compensate for the effect of diverting water around the St. Marys River rapids for power. Construction of the gated dam was required by the International Joint Commission as a condition to approval of the water diversion. By operation of the gates and changes in power diversions, flows specified by the regulation plan can be achieved.

Lake Ontario has been regulated since 1960 by means of a control dam that spans the St. Lawrence River near Iroquois, Ontario, and by a powerhouse and dam at Barnhart Island, New York, near Cornwall, Ontario. Control of Lake Ontario was authorized by the International Joint Commission as part of the St. Lawrence Seaway and Power Project to meet the criteria specified in the Orders of Approval of the International Joint Commission. The present regulation plan being used to determine the release of water through these structures is known as "Lake Ontario Regulation Plan 1958–D."

The present regulation of Lakes Superior and Ontario is governed by criteria that relate primarily to a specified area associated with each Lake. In recent years, as regulation procedures have improved and shoreline development intensified, it has become apparent that additional benefits might be achieved through a more systematic approach to Great Lakes regulation. New regulation systems, for example, on Lake Superior, would benefit Lakes Michigan, Huron, and Erie without detriment to the major interests on Lakes Superior and Ontario.

In October 1964 the governments of the United States and Canada asked the International Joint Commission to "determine whether measures can be taken to regulate further the levels of the Great Lakes for the purpose of bringing about a more beneficial range of stages for, and improvement in affected shore property, navigation and power interests." The Commission appointed the International Great Lakes Levels Board to conduct the investigation. The Board submitted a final report to the International Joint Commission late in 1973.

Improved or further regulation of the Great Lakes system could consist of controlling the levels and outflows of all or various combinations of the Lakes. Lakes Michigan and Huron are treated as a single lake since they react hydraulically as one, and no control is present at the Straits of Mackinac. Any combination which included either Lake Erie or Lakes Michigan-Huron would require engineering construction in their outlet rivers, the Niagara and the St. Clair–Detroit Rivers respectively, since these are presently unregulated. Need for changes in the existing control facilities in the St. Marys and St. Lawrence Rivers would depend on whether such changes were economically desirable.

This appendix considers in detail problems related to the various artificial factors which affect lake levels and outflows. These artificial factors include diversions, connecting channel changes, increased consumptive loss of water, and extension of the navigation season on the Great Lakes. The latter will require detailed hydraulic studies and close operational surveillance of connecting channels.

Projected consumptive use of water within the Basin could significantly affect the levels of the Great Lakes. Procedures will be required to reduce future consumptive use and its effects.

The relationships of many of the factors which affect the fluctuation of the lake levels are not completely understood. This situation could be improved by an active physical research program extending the engineering studies currently in progress for the International Joint Commission's study.

Precipitation on the Great Lakes and on their tributary land areas is the source of all the water entering the Lakes. On the average, more than half of this water is removed from the Lakes by evaporation. Variations of these two factors are largely responsible for the long-term water level fluctuations. Further investigation of these factors is essential for more effective management of lake levels.

It is expected that the intensive research efforts under way in the International Field Year on the Great Lakes, a part of the International Hydrologic Decade, will be helpful in providing a better understanding of Lake Ontario and the other Great Lakes. The Great Lakes Basin Commission's special Great Lakes study, *Limnological Systems Analysis of the Great Lakes*, will also provide invaluable insights into the complex interrelationship among the various subsystems which constitute the lake environment.

FOREWORD

The North Central Division, U.S. Army Corps of Engineers, was assigned the responsibility of coordinating the levels and flows study. The material here was furnished primarily by the Department of the Army, Corps of Engineers, Detroit District, Buffalo District, and North Central Division, and the Lake Survey Center, National Ocean Survey, National Oceanic and Atmospheric Administration, Department of Commerce. This appendix was compiled by the Levels and Flows Work Group, a panel appointed by the Great Lakes Basin Commission to help prepare a comprehensive, coordinated, joint plan for use and development of water and related land resources.

The appendix was prepared under the supervision of Stewart H. Fonda, Jr., by Donald J. Leonard, Alternate Chairman; and Joseph Raoul, Jr., all of North Central Division, Corps of Engineers. Leonard T. Schutze, Detroit District, Corps of Engineers, and Donald M. Liddell, Buffalo District, Corps of Engineers, assisted in the preparation of a number of writeups. In 1971 Salvatore Maiore replaced Mr. Liddell as member from Buffalo District office. Personnel of the Michigan Department of Natural Resources, represented by Dale Granger, Leon Cook, Herbert Miller, Mogens Nielsen and George Taack, assisted in preparing a number of planning subarea writeups. Colonel C.T. Foust (retired), Ohio Department of Natural Resources; Murray Pipkin, Illinois Division of Waterways; and Nicholas L. Barbarossa, Federal Water Resources Council, formerly with the New York State Department of Environmental Conservation, added data for several planning subarea writings.

Others who participated in the work efforts of this appendix were Huson A. Amsterburg, Soil Conservation Service, U.S. Department of Agriculture, subsequently replaced by Sterling E. Powell of that office in 1971, and Sumner A. Dole, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior.

Assistance in updating levels and flows data was provided by Frank A. Blust, Alan W. Hodson and James S. Moore (retired) from Lake Survey Center, National Ocean Survey, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

The Levels and Flows Work Group included representatives from the following Federal agencies: Bureau of Sport Fisheries and Wildlife, Department of the Interior; Federal Power Commission; Soil Conservation Service, Department of Agriculture; Buffalo District, Corps of Engineers; and Detroit District, Corps of Engineers. State agencies represented included: Illinois Division of Waterways; Michigan Department of Natural Resources; New York State Department of Environmental Conservation; Ohio Department of Natural Resources; and Wisconsin Department of Natural Resources.

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INTRODUCTION

Purpose

Appendix 11, *Levels and Flows*, describes the Great Lakes system and the physiography of its basins. It analyzes the natural and artificial factors that affect the levels and flows of the Lakes, describes the extremes of levels and their frequency, and provides general criteria that should be considered in regulating the Lakes. This appendix also discusses the effects of fluctuating lake levels on land management, zoning, water use, and recreation. Low water level conditions as well as high water levels damage Great Lakes interests.

Scope of Study

In analyzing the problems and needs related to the levels and flows of the Great Lakes, their connecting channels, and the St. Lawrence River, this appendix emphasizes the need for more research and engineering investigations. It suggests constraints dealing with water withdrawals and uses of Great Lakes waters in addition to the Boundary Waters Treaty of 1909. It also identifies the implications of diverting large supplies of water into or out of the Great Lakes as well as effects on pertinent interests such as power, shore property, and navigation.

In the ongoing study being conducted by the International Joint Commission on Water Levels of the Great Lakes, possible alternative regulation plans are being developed based on several assessments. One assessment will be the benefit-cost ratio for providing the plan(s) for further regulation. Criteria to assess the ecological, sociological, and aesthetic aspects are being developed. The findings of the Corps of Engineers, reported in December, 1965, "Water Levels of the Great Lakes, Report on Lake Regulation" supplements available information from the current International Joint Commission study.

Hydraulic and hydrologic data pertinent to the Great Lakes are contained in the following published reports:

(1) *Lake Erie Outflow 1800–1964*, by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, dated June 1965. This contains data on Lake Erie outflows, diversion from Lake Erie into Welland Canal and New York State Barge Canal diversions.

(2) *Lake Ontario Outflows 1860–1954*, by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, dated June 1970. This contains data on Lake Ontario outflows and total diversion through navigation and power canals.

Copies of these reports are available from the North Central Division office, U.S. Army Corps of Engineers, in Chicago, Illinois. Historical data on the outflows of the St. Clair and Detroit Rivers and diversions for the Ogoki-Long Lake Projects, Chicago Sanitary and Ship Canal and Illinois-Michigan Canal are included in the Addendum.

Derived data on ultimate water levels for the reaches listed in Table 11–34 are available at the North Central Division office.

A publication prepared by Lake Survey Center, National Oceanic and Atmospheric Administration, entitled *Great Lakes Water Levels, 1860–1970*, contains Great Lakes water level gage data providing monthly and annual levels for all current permanent gages in Lake Survey Center's network for the period of existence. The publication also contains (in a separate table) the average monthly mean levels and the highest and lowest monthly mean levels for the period of record, plus the average monthly mean levels for the period 1960 through 1970. This publication can be purchased from Lake Survey Center.

When this appendix was prepared in September 1972, the International Great Lakes Levels Board's study was still under way. The Levels Board's Main Report was submitted to the International Joint Commission on December 15, 1973, and made public on February 26, 1974. To the extent possible, this appendix has been updated accordingly. However, the data presented in the appendix have not been extended beyond the period used in 1972. The impact of the record levels experienced on the downstream Lakes in 1973–1974 has not been addressed in this appendix.

Section 1

LAKE LEVELS—REGULATION OF THE GREAT LAKES

1.1 General

The Great Lakes cover approximately 95,000 square miles and drain a land area approximately twice as large. Figure 11–1 is a map of the plan areas. The immense storage capacity of the Lakes combined with their restricted outflow capacities make them a highly effective, naturally regulated water system.

Natural regulation is the limited variation in levels and outflows from summer to winter and from extreme low to extreme high during a period of record. On Lakes Superior, Michigan, and Huron the normal range in monthly mean water levels from winter low to summer high is only one foot; on Lake Erie, approximately one and one-quarter feet; and on Lake Ontario, one and one-half feet.

Since 1860 the monthly levels of Lake Superior from extreme low to extreme high have varied four feet; for Lakes Michigan, Huron, and Ontario the range has been six and one-half feet; and for Lake Erie, five and one-quarter feet.

Maximum flows of the outlet rivers are only two to three times their minimum. This extreme stability is in marked contrast to the wide range of flows of several other North American rivers. For example, the ratio of maximum to minimum flow for the Mississippi River at St. Louis, Missouri is 30 to 1; for the Columbia River, 35 to 1; and for the Saskatchewan River, nearly 60 to 1.

A regulation plan is an established procedure comprising predetermined rules and criteria for discretionary control on the lake outflows to accomplish pre-designed results. Lake regulation implies the operation of one or more structures at the outlet of a lake. These structures control the outflow through gated works. The objectives of regulation are to provide a range of lake levels acceptable to various interests, while maintaining satisfactory downstream level and flow conditions.

1.2 Great Lakes Regulation

Lakes Superior and Ontario are currently regulated in accordance with Orders of Approval of the International Joint Commission and under supervision of the Commission's International Lake Superior Board of Control and International St. Lawrence River Board of Control. Regulation is carried out within the control limits of the regulation criteria by employing existing regulatory works. The regulated levels of these Lakes follow closely the natural pattern of lake levels during normal supply periods. Significant departures from the natural pattern occur only during periods of high or low water supply, particularly when these conditions are expected to continue for many months.

During the 1964-65 period of extreme low levels, downstream conditions were eased slightly by releasing additional water from Lake Superior where supplies and storage conditions were more favorable. The time lag in the system limited downstream beneficial effects of the extra water flow. During the 1964-65 period, additional water stored in Lake Ontario improved the levels of the Lake and subsequent discharges of the St. Lawrence River.

As to the regulation of Lakes Superior and Ontario, the governments of Canada and the United States have agreed upon the criteria contained in the International Joint Commission's Orders of Approval. To regulate Lakes Michigan-Huron (hydraulically considered one lake) and Erie, different criteria are required. Extending the regulation of the Great Lakes system by controlling outflows from Lakes Michigan, Huron, and Erie presents serious, complex, and challenging engineering and economic problems.

The International Joint Commission study was directed, in part, to establishing criteria for the presently unregulated Lakes. Findings also include a review of existing criteria for

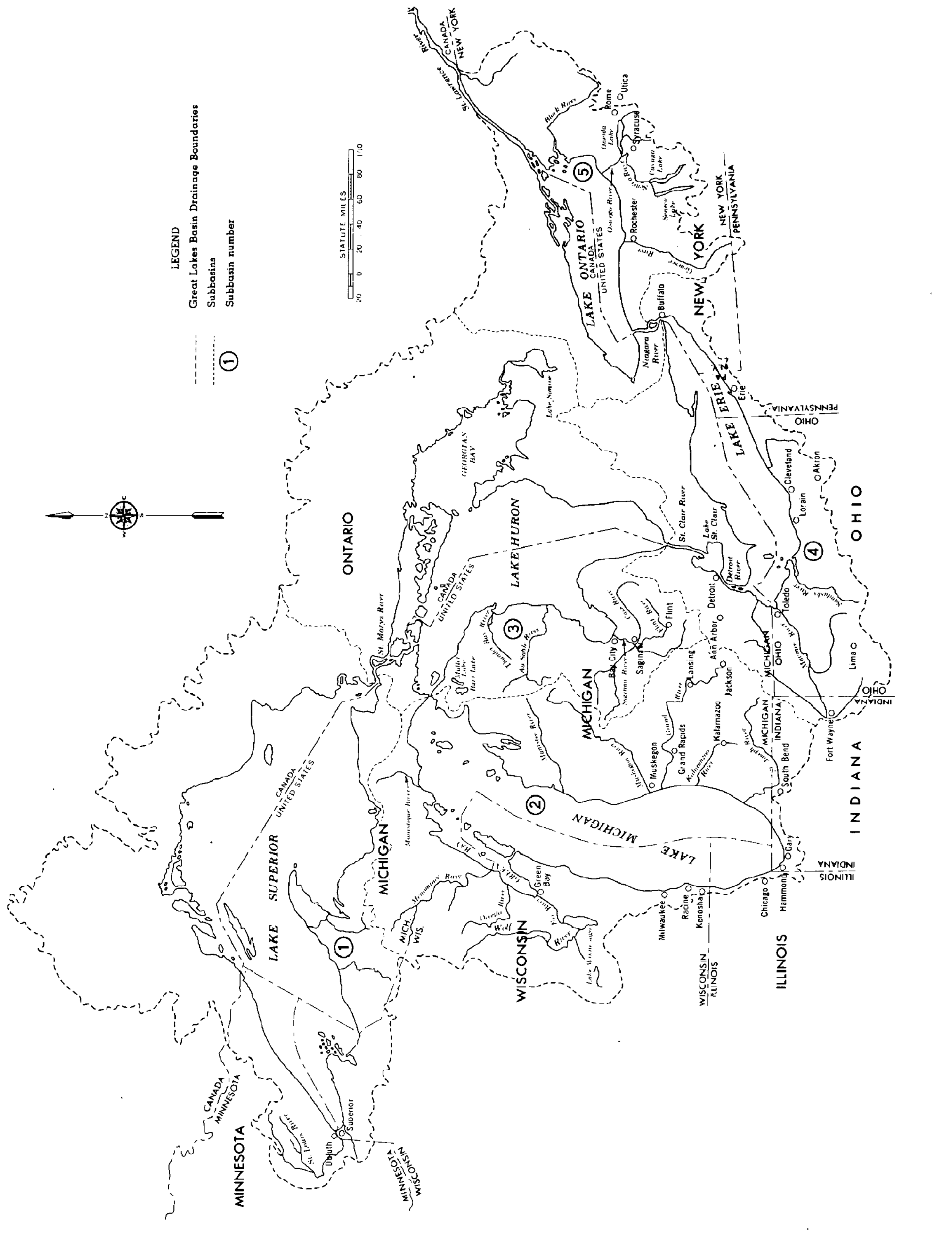


FIGURE 11–1 Great Lakes Basin Plan Areas

Lakes Ontario and Superior.

It has been suggested by interested investigators that the Lakes be maintained at constant levels. This is not feasible. Consider, for example, the problem of stabilizing the levels of Lakes Michigan and Huron, most difficult of all the Lakes to stabilize because of their large combined water area. To keep such levels constant, it would be necessary at times to greatly increase the supply of water to these Lakes, and at other times to increase the St. Clair River flow to nearly triple the river's present maximum discharge capacity.

Lakes Michigan-Huron have a storage area of approximately 45,000 square miles and Lake Erie, immediately downstream, an area of only 10,000 square miles. If large amounts of water were released quickly from Lakes Michigan-Huron, Lake Erie levels would be affected adversely by the rapid inflows. If these releases were passed on down the system, Lake Ontario and the St. Lawrence River would also suffer from extreme high water conditions.

While the maintenance of constant levels is not feasible, some reduction might be achieved in the range of water levels of the presently unregulated Great Lakes. Such regulation would still require comparatively large or small releases of water. If meteorological conditions could be anticipated far enough in advance, the magnitude of the flow variations could be reduced by allowing sufficient time to gradually discharge the potential surplus volume of water without damaging effects. Conversely, the supervising Board of Control could gradually store water surpluses during periods of average or high supplies to meet anticipated periods of low supplies. However, present techniques cannot provide weather forecasts far enough in advance. Therefore, any regulation plans developed must rely upon the analysis of past records and upon tests of the effects of the plans on the various interests involved.

1.2.1 Joint Canada–United States Study

Directed by the International Joint Commission, the joint Canada-United States study is determining whether measures within the Great Lakes Basin can be taken to regulate further the levels of the Great Lakes, or any of them and their connecting channels, so as to reduce occurrence of extreme levels.

Variations in the levels and the outflows of the Great Lakes primarily affect shore property, navigation interests, and hydroelectric power output. The study evaluates the effects of the test regulation plans. It establishes regulation criteria and evaluates improved plans. The study has developed design concepts for desirable regulatory works. The cost estimates will determine the economic justification.

Present studies are formulating regulation plans and testing these plans on past sequences of water supplies to the Lakes. The studies use devising-and-testing procedure to develop beneficial plans, such as a desired reduction in the extremes of lake stage. In recognizing that future supply sequences will not duplicate those of the past, the studies have developed a means of simulating a long period of supplies, the statistical characteristics of which conform closely to those of the historic supplies.

1.2.2 Framework Study Relationship

Levels and flows studies for the *Great Lakes Basin Framework Study* will consider factors affecting the levels and regulation of the Great Lakes, natural and artificial factors affecting lake levels, and extreme levels and their frequency. Analysis of the affected areas will determine the need for lake regulation. The nature, quality, and quantity of these needs will also depend upon the demands for water withdrawal and other uses of Great Lakes waters.

In order to satisfy the needs of levels and flows, alternative regulation plans are needed for those Lakes presently unregulated, and plans for already regulated Lakes should be improved. This could be achieved by adding new structures and improving existing structures, or by further excavation of connecting channels.

The data output of levels and flows studies will provide information required in studies dealing with shore use and erosion, water supply, water quality, navigation, flood plains, land use, irrigation, fish, wildlife, recreation, and aesthetic and cultural aspects. The influence of levels and flows on these studies will be discussed later.

Section 2

PHYSIOGRAPHY OF THE GREAT LAKES BASIN

2.1 General

The Great Lakes Basin consists of five individually connected drainage basins and lies between the latitudes of 40°30′ and 50°30′ north and between the longitudes of approximately 75°20′ and 93°10′ west. According to Executive Order 11345 the GLBC area of influence also includes tributaries discharging into the St. Lawrence River within the United States. The maximum dimensions of the Great Lakes Basin are approximately 740 miles measured north-south and 940 miles east-west. One Lake occupies each basin, except for the Erie basin which contains Lakes Erie and St.Clair.

A remarkable feature of the Great Lakes drainage basin is that its water covers approximately one-third of the total Basin. The water surface area ranges from 23 percent of the total basin area for Lake Ontario to 39 percent for Lake Superior. Table 11–1 shows the percentage of each Lake basin covered by water.

The Great Lakes system comprises a chain of Lakes with connecting channels. The outflow from each Lake, except Lake Ontario, is discharged into the next Lake downstream. Lakes Superior and Michigan discharge flows into Lake Huron, and in turn, into Lakes St. Clair, Erie, and Ontario. The Lake Ontario discharge flows out of the Great Lakes Basin through the St. Lawrence River into the Atlantic Ocean. Figure 11–2 is a profile, utilizing an exaggerated vertical scale, showing the Great Lakes-St. Lawrence River system.

TABLE 11–1 Percent of Lake Basins Covered by Water

Lake Basin	Percent
Superior	39
Michigan	33
Huron	31
Erie, including Lake St. Clair	26
Ontario	23
All Lakes	32

Measured along the Great Lakes sailing courses, the distance from the western end of Lake Superior to the Atlantic Ocean is approximately 1700 miles. From the east end of Lake Ontario to the Atlantic is 600 miles. Lake Michigan, like Superior, is connected only with Lake Huron. Lakes Michigan and Huron have approximately the same water level, and the flow between them may be in either direction, depending upon wind, weather, and barometric conditions. Net flow is out of Lake Michigan. Length, breadth, and shoreline dimensions of each Lake are shown in Table 11–2.

2.1.1 Lake and Land Areas

The Great Lakes and their tributary land areas make up a major part of the St. Lawrence River drainage basin. Water from the Great Lakes drainage basin flows through the river to the Atlantic Ocean. Lakes Superior, Michigan, Huron, Erie, Ontario, and St. Clair have a total water surface area of 95,000 square miles, including 235 square miles of St. Lawrence River water surface terminating at the International Powerhouse near Massena, New York. The total land and water area of the Great Lakes Basin is approximately 296,000 square miles.

Table 11–3 lists the land and water areas of the individual Lake basins of the Great Lakes and Lake St. Clair. The tabulated data show that the land area tributary to Lake Superior is approximately 1.6 times the size of the Lake area; the local land area tributary to Lakes Michigan and Huron is approximately 2.2 times the combined areas of the Lakes. Land tributary to Lake Erie is approximately 2.4 times the Lake area, while land tributary to Lake Ontario is approximately 3.4 times the Lake area. Total basin areas do not necessarily equal the sum of their component parts because of rounding.

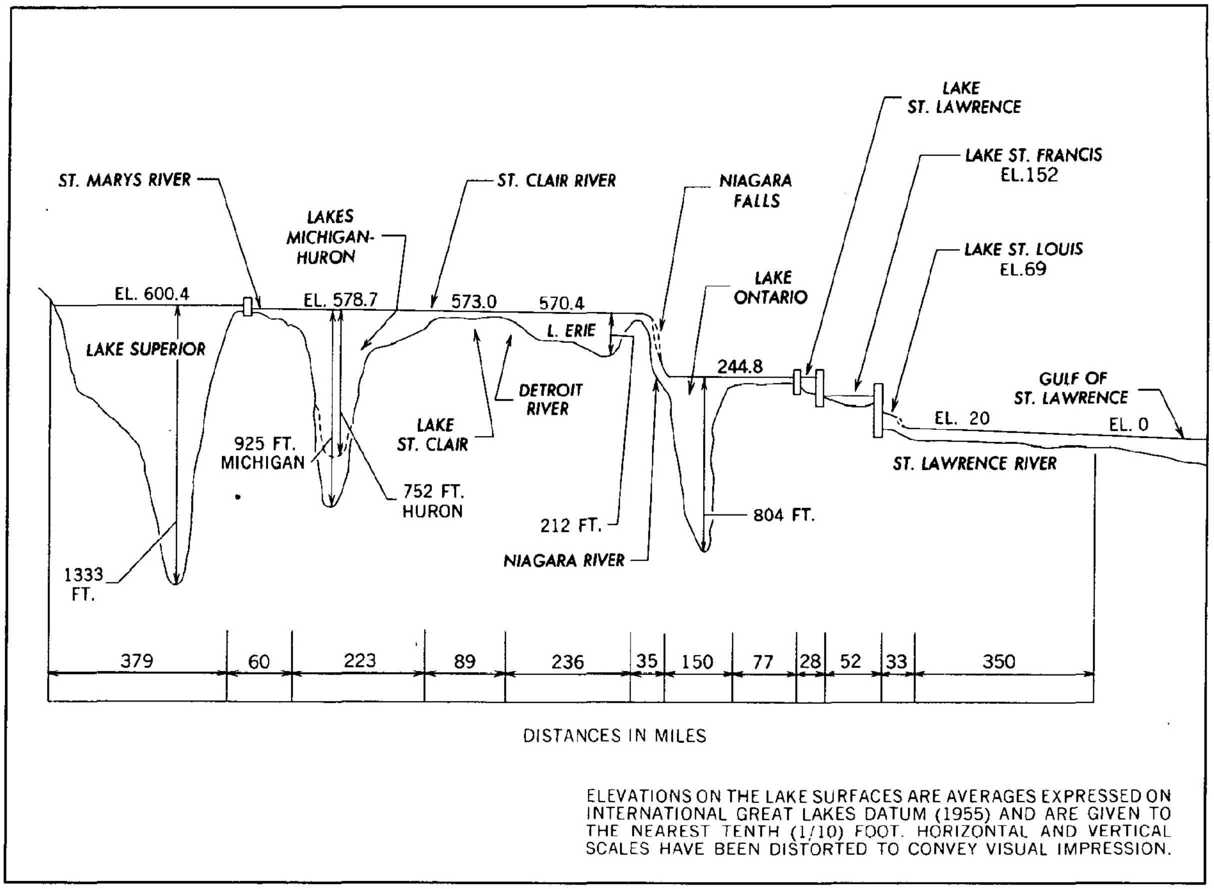


FIGURE 11-2 Profile of the Great Lakes System

The St. Lawrence River drainage basin above the International Powerhouse is 3,010 square miles in area, including 235 square miles of river water surface. The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data prepared the above data. An additional 3,200 square miles includes the drainage area to the International boundary (GLBC area of influence also includes U.S. tributaries discharging into the St. Lawrence River) consisting of the Grass, Raquette, and St. Regis tributary areas.

2.1.2 Lake Volumes

When the Great Lakes rise from their low water levels to their highest recorded, the water volume increases only 1.3 percent, from 5,475 cubic miles to 5,550 cubic miles. With the lake levels at low water datum the total volume of the water in all of the Lakes is approximately 18.5 billion acre-feet. Lake Superior contains 54 percent of the water; Lake Michigan, 22 percent; Lake Huron, 15 percent; Lake Erie, 2 percent; and Lake Ontario, 7 percent.

The volume of Lake Erie varies from nearly 112 cubic miles to 122 cubic miles during the transition from record low water level to record high water level. The mean depth of the Lake changes from 59.7 feet to 64.5 feet. However, the water surface area increases only 10 square miles during the transition from low water level to high water level. The increase in water surface area is greatest in the west basin where the depth is shallowest. Volumes of the other Lakes are listed in Table 11-2.

Measured from low water datum, the greatest known and average natural depths respectively of the Great Lakes and Lake St. Clair are: Lake Superior, 1,333 feet and 489 feet; Lake Michigan, 923 feet and 279 feet; Lake Huron, 750 feet and 195 feet; Lake St. Clair, 23 feet and 10 feet; Lake Erie, 212 feet

TABLE 11-2 General Great Lakes Information

Description	Lake Superior	Lake Michigan	Lake Huron	Lake St. Clair	Lake Erie	Lake Ontario	Total
Low Water Datum (LWD) Elevation in feet IGLD (1955)	600.0	576.8	576.8	571.7	568.6	248.8	
Dimensions in miles:							
Length	350	307	206	26	241	193	
Breadth	160	118	183	24	57	53	
Shoreline including islands	2,980	1,660	3,180	169	856	726	9,571
Areas in square miles:[1]							
Drainage basin in U.S.	37,500	67,900	25,300	2,370	23,600	16,800	173,470
Drainage basin in Canada	43,500	0	49,500	4,150	9,880	15,300	122,330
Total drainage basin (land & water)	81,000	67,900	74,800	6,520	33,500	32,100	295,800
Water surface in U.S.	20,600	22,300	9,100	162	4,980	3,460	60,602
Water surface in Canada	11,100	0	13,900	268	4,930	3,880	34,078
Total water surface	31,700	22,300	23,000	430	9,910	7,340	94,680
Volume of water in cubic miles:[1]	2,935	1,180	849	1	116	393	5,474
Depths of water in feet:[1]							
Average over lake	489	279	195	10	62	283	
Maximum observed	1,333	923	750	21[2]	210	802	
Outlet river or channel	St. Marys River	Str. of Mackinac	St. Clair River	Detroit River	Niagara River	St. Lawrence River	
Length in miles	70	---	27	32	37	502	
Average flow in CFS (1860-1970)	75,000	52,000	187,300	190,000	201,900	239,200	
Monthly Elevations in feet[5]							
Average (1860-1970)	600.38	578.68[3]	578.68[3]	573.05[4]	570.39	244.77	
Maximum	602.06	581.94	581.94	575.70	572.76	248.06	
Minimum	598.23	575.35	575.35	569.86	567.49	241.45	
Average - winter low to summer high	1.1	1.1	1.1	1.6	1.5	1.8	
Maximum - winter low to summer high	1.9	2.2	2.2	3.3	2.7	3.5	
Minimum - winter low to summer high	0.4	0.1	0.1	0.9	0.5	0.7	
Annual precipitation in inches (1900-1970)							
Average on basin (land & water)	30	31	31	----	34	34	
Average on lake surface	30	30	31	----	33	33	

[1]Lake level at Low Water Datum elevation. LWD is a reference elevation for nautical charts and projects.

[2]Maximum natural depth.

[3]The Straits of Mackinac between Lakes Michigan and Huron is so wide and deep that the difference in the monthly mean levels of the lakes is not measureable.

[4]Lake St. Clair elevations are available only for the period 1898 to date.

[5]Lake elevations are as recorded at Marquette (L. Superior), Harbor Beach (L. Michigan-Huron), Grosse Pointe Shores (L. St. Clair), Cleveland (L. Erie), and Oswego (L. Ontario). Recorded elevations are affected by man-made changes such as: regulation of outflows from Lake Superior (1921) and Lake Ontario (1960); diversions of water from Hudson Bay basin into Lake Superior (1939) and from Lake Michigan basin into Mississippi basin at Chicago (before 1860); and regimen changes in the natural outlet channels from the lakes throughout the period of record.

NOTE: Area data shown above were prepared by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. Total basin areas do not necessarily equal the sum of their component parts due to rounding.

and 64 feet; and Lake Ontario, 802 feet and 283 feet. The average depth over the entire surface of the Great Lakes is approximately 305 feet.

2.1.3 Outflow Rivers

The Great Lakes system is a chain of Lakes and connecting channels. Lake Superior discharges from its eastern end through the St. Marys River into Lake Huron. The fall in the St. Marys River (70 miles) from Lake Superior to Lake Huron is 22 feet. Most of the fall occurs in the mile-long St. Marys Falls located near Sault Ste. Marie.

The Straits of Mackinac provide a broad and deep connection between Lake Michigan and Lake Huron. More than three miles wide at their narrowest location, the Straits vary in depth to more than 200 feet.

The flow from Lake Michigan into Lake

TABLE 11-3 Great Lakes Land and Water Areas in Square Miles

Lake Basin	Water Area	Land Area	Total Area
Superior	31,700	49,300	81,000
Michigan	22,300	45,600[1]	67,900
Huron	23,000	51,800[2]	74,800
St. Clair	430	6,090[3]	6,520
Erie	9,910	23,600[4]	33,500
Ontario	7,340	24,700	32,100
Total	94,680	201,090	295,800

[1] Including St. Marys River

[2] Including St. Clair River

[3] Including Detroit River

[4] Including Niagara River

Huron averages 52,000 cfs. The slope required for this movement of water is imperceptible. The average elevation of these two Lakes is about the same. Lakes Michigan and Huron, for hydraulic purposes, are treated here as though they were one lake, with the St. Clair River its outlet.

The St. Clair River (27 miles long) extends from the southern end of Lake Huron to Lake St. Clair, the outlet of which is the Detroit River (32 miles long) discharging into Lake Erie. From Lake Huron to Lake St. Clair the fall is five feet; from Lake St. Clair to Lake Erie, it is approximately three feet. The St. Clair and Detroit Rivers do not have rapids or falls.

Lake Erie discharges at its eastern end through the Niagara River (37 miles in length) into Lake Ontario. The fall from the Lake Erie level to Lake Ontario is 326 feet, more than one-half of which occurs at Niagara Falls. The cascades immediately above the Falls and the rapids downstream from the Falls account for nearly 150 feet of the remaining total fall.

Lake Ontario discharges at the eastern end through the St. Lawrence River which is the natural outlet for drainage from the Great Lakes. Lake Ontario is 245 feet higher than Father Point, Quebec. This marks the river's transition into the Gulf of St. Lawrence, which is essentially at sea level. From Lake Ontario, downstream 68 miles through the Thousand Islands section (to four miles east of Ogdensburg, New York), the drop is approximately one foot; in the next 47 miles through the International Rapids section, it is nearly 92 feet. Development in the International Rapids section includes Iroquois Dam in the vicinity of Iroquois Point, a dam in the Long Sault Rapids between Barnhart Island and the New York shore, and the International Powerhouse crossing the International Boundary from the downstream end of Barnhart Island to Canadian shores.

The International Rapids section extends to the head of Lake St. Francis. Beyond this point the St. Lawrence River flows entirely within the borders of Canada. In the next 72 miles to Montreal Harbor, the St. Lawrence River falls another 132 feet. In the 340 miles from Montreal Harbor to Father Point, the fall is approximately 20 feet.

2.2 Lake Superior

Lake Superior is the highest, largest, and deepest of the Great Lakes. Water surface is 600 feet above sea level. Its maximum depth is 1,333 feet. The lake depths extend 733 feet below sea level. Lake Superior basin covers 27 percent of the upper Great Lakes Basin. The distance from its shore to the perimeter of its basin varies from 2 to 75 miles, except near Lake Nipigon where the distance is 150 miles.

An escarpment near the lakeshore rises 400 to 800 feet above the lake surface on all sides except the southeast. This escarpment and the western lake bottom consist of very hard, metamorphosed Precambrian age rock formations that formed the highlands bordering a large trough or synclinal basin. Several hundred million years of erosion have worn down the rugged highlands until they are part of the undulating plain. Rock formations southeast of Lake Superior are of the early Paleozoic age. The southeastern lakeshore and lake bottom are largely underlain by sandstone and limestone.

The continental glaciers that swept across Canada and the northern United States during the ice ages rounded and smoothed the ridges of hard rock and gouged out the softer rocks and sediments within the syncline or preglacial Lake Superior basin. As they retreated, the glaciers and glacial lakes covered the land surface with a thin layer of drift. Irregularities and deep canyons in the western part of the Lake basin are filled with sediments, making the lake bottom smooth. In contrast, depressions in the eastern part of the lake basin are not filled. The eastern lake bottom has many irregular north-south submarine ridges and canyons.

While the glacial-lake water levels were receding, waves carved ancient lake terraces, resembling gigantic stair steps, into the shoreline. These wave-cut terraces show that the surface area of one of the ancient lakes in the vicinity of these basins was very large. It covered an area greater than the total combined area of Lakes Superior, Michigan, and Huron.[28] The wave-cut terrace of this ancient lake is now above present Lake Superior water levels. After the tremendous weight of continental glaciers was removed, isostatic rebound and tilting of the land surface elevated these terraces.

Several channels have drained the Lake Superior basin at different times. During periods when glacial ice filled most of the basin and closed the eastern outlets, meltwater surface was high and water flowed from the west end of the basin through the Brule and St. Croix River valleys into the Mississippi River. When the glaciers retreated and the eastern outlets were opened, water was lowered almost to present levels and flowed into Lakes Huron and Michigan through abandoned river valleys across the Upper Peninsula of Michigan or through the St. Marys River valley.

Outcropping sandstone layers in the St. Marys River form a natural weir that restricts the outflow of Lake Superior. Man has controlled Lake Superior outflows since 1921 when engineers constructed the Sault Ste. Marie control works across the rapids.

2.3 Lake Huron

Lake Huron is in the central portion of the Great Lakes Basin, southeast of Lake Superior and east of Lake Michigan. It receives outflow from Lake Superior through the St. Marys River, a channel 70 miles long. It also receives outflow from Lake Michigan through the Straits of Mackinac. Lake Huron's water surface is 579 feet above sea level. Its maximum depth is 752 feet.

Three predominant rock formations command the Lake Huron basin topography from north to south. Near the north shore, which is the southern margin of the Canadian Shield, is a low, south-facing escarpment of Precambrian formations. The second escarpment is a ridge of Silurian age limestone and dolomite, called the Niagaran Escarpment, that forms Manitoulin Island and Saugeen Peninsula. This ridge parallels the north shore of Lake Huron and separates the main body of the Lake from North Channel and Georgian Bay.

The third escarpment is a submerged but prominent ridge, roughly parallel to the Saugeen Peninsula and Manitoulin Island, that extends across the Lake from Alpena, Michigan to Kincardine, Ontario. The deepest waters of the Lake occur in irregular depressions north of this ridge. South of this ridge the lake bottom is smoother. Saginaw Bay is southwest of the ridge.

Land and lake bottom topography south of the Canadian Shield features many ridges and valleys with sedimentary rock formations and modifications resulting from erosion. The outcrop pattern of the formations resembles concentric circles with their centers in the central part of the Lower Peninsula of Michigan. These formations dip gently toward central Michigan, making a bowl-shaped structural feature called the Michigan Basin.

During the Ice Age, continental glaciers deepened preglacial lowlands, gouged out softer rock formations on the north and east sides of the Michigan Basin, and formed Lake Huron. The moving glaciers stripped soil from the rock surfaces and exposed the Niagaran Escarpment that is prominent throughout the Great Lakes area. Retreating glaciers filled depressions with glacial drift and glacial lake deposits, and carved glacial-lake terraces into the shoreline.

The outflow from Lake Huron passes through an outlet channel composed of the St. Clair and Detroit Rivers and Lake St. Clair. There are no artificial controls in the channel between Lakes Huron and Erie, but dredging operations in this watercourse over the years have made a deeper channel, with a substantial lowering of the water levels of Lakes Michigan and Huron. The St. Clair River carries Lake Huron outflow 27 miles into Lake St. Clair with a fall of five feet.

2.4 Lake Michigan

Lake Michigan is in the west central portion of the Great Lakes Basin, south of Lake Superior and west of Lake Huron. Lake Michigan has a water surface 579 feet above sea level and has a maximum depth of 923 feet. It is connected to Lake Huron by the Straits of Mackinac.

Direction of currents in the Straits alternates from east to west depending upon barometric pressure and wind conditions. The net flow, however, is eastward. Northern outflow goes into Lake Huron. A southern outflow of 3,200 cfs is diverted into the Mississippi River basin at Chicago. The physiography of the Lake Michigan basin results from glacial deposits. Bedrock exposures are not common.

Lake Michigan is bounded on the west and north by the Niagaran Escarpment, which dips under the Lake toward its basin. The relatively smooth slope of the lake bottom from the shore to the depths on the west and northwest sides of the Lake is essentially a dip-slope on the Niagara carbonate rocks.[15]

The lake bed has four regions: a smooth basin to the south; a divide; a northern basin; and a submarine ridge and valley province to the northeast. The smooth area has a maximum depth of 564 feet and resembles a huge bowl with gently sloping sides. The bottom materials consist of sand along the shore, gravel between 50 and 100 feet depth, and mud below the deep water. These sediments fill depressions and smooth the lake bottom. The divide is a large mid-lake area less than 400 feet deep. This shallow area of the lake bottom consists of two limestone ridges overlain by coarse sediments. Thin beds of sand have been found on the east shoreline down to 120 feet depth, and on the west shoreline to depths ranging from 50 to 300 feet. The northern basin contains ridges and valleys trending northeast-southwest. The deepest point in the Lake, 925 feet deep, is in this region. The submarine ridge and valley province are northeast of the northern basin. In this area the bottom has numerous deep troughs of 250 to 500 feet, separated by ridges with only 25 to 50 feet of water over them. Most of the valleys and ridges have a north-south orientation with greater depths toward the south and southwest where this province merges with the northern basin.

At the basin's western end is Green Bay. The Door Peninsula, formed by the Nigaran Escarpment, divides the embayment from the Lake. Water depths vary from an average of 75 feet to a maximum of 160 feet. Mud deposits cover the deeper floors. Sandy deposits, broken by bedrock outcrops, cover the shoreline slopes that extend various distances under the water.

A relatively shallow shelf starts approximately 45 miles west of the outlet of Lake Michigan and extends eastward through a narrow canyon into Lake Huron. It is an ancient river valley that now forms the major part of the Straits of Mackinac. A variety of sediments covers the bottom of this area. Lake Michigan was formed during the Ice Age when continental glaciers gouged out the Lake Michigan lowland, and removed the overburden and softer rock formations, leaving ridges of harder, more resistant rock. When the glaciers retreated they buried the rock outcrops and filled many of the valleys and troughs with glacial till, outwash, and glacial-lake sediments. A major outlet for the ancient glacial lakes in the Lake Michigan basin was near Chicago.[1] Water flowed south out of the basin through the Illinois River valley into the Mississippi River. This natural outlet no longer exists because of the lower postglacial levels of the Lake. Enormous quantities of beach sand and sand dunes have accumulated along the shore at the south end of the Lake.

2.5 Lake St. Clair

The Michigan courts officially define Lake St. Clair as a Great Lake. These courts assert the rights and interests of the State of Michigan as proprietor and trustee of the water and submerged lands of Lake St. Clair. The lake has a surface area of 430 square miles and a natural maximum depth of 23 feet. It is 26 miles long, with marshy shores and a gently sloping bottom. Situated in glacial deposits, the lake has ridges of glacial till (moraines) to the north and the south.[28]

The St. Clair River from Lake Huron flows into Lake St. Clair from the north. A small delta marks the north central and northwest areas of the lake. The Detroit River drains Lake St. Clair and empties into Lake Erie, falling approximately three feet in 32 miles.

2.6 Lake Erie

Lake Erie, 570 feet above sea level, is south of Lake Huron and southwest of Lake Ontario. Surface area is 9,910 square miles, approximately one-thirteenth the area of Lake Superior. It is the only Lake in the system whose point of greatest depth is above sea level. Average depth is 62 feet. From the shallows in the western end, the bottom slopes eastward to a maximum of 212 feet.

The Lake Erie basin is divided into three areas. The western basin is relatively shallow and covered with fine sediments. The Detroit River discharge produces a flow pattern that penetrates far south into Lake Erie's western basin, and is traceable eastward through the northern islands area into the central basin. The western basin is underlain by hard limestone and dolomite that resist erosion. There are many shallow areas, ridges, and islands. Most of the central and eastern basins were excavated in soft easily-eroded shales of Devonian age. Part of this lake bottom is a resistant Devonian limestone.[15] Although the rock in the two basins was similar, glaciers excavated the eastern basin deeper than the central. A submerged ridge of sand and gravel separates the central basin from the eastern.

Nearly 6,300 square miles in area, the central basin of Lake Erie is the largest of the three basins. It has a smooth, flat bottom. The eastern basin is a deepened extension of the central one. Glacial erosion deposits cover adjacent shorelands and deeper lake bottom areas. Occasional sand deposits are found along the shores.

The northern and western boundaries of the Lake Erie drainage basin are transitional and poorly defined. The obvious southeastern boundary adjoins the Appalachian Plateau.

Lake Erie discharges primarily at its eastern end, through the 37-mile Niagara River into Lake Ontario. More than one-half of the 326-foot fall from Lake Erie to Lake Ontario occurs at Niagara Falls, where the river crosses the Niagaran Escarpment. Lake Erie water is also diverted into Lake Ontario through the Welland Canal.

2.7 Lake Ontario

Lake Ontario's water surface is approximately 245 feet above sea level. It is approximately 804 feet deep at its deepest location, where the bottom is 561 feet below sea level, lower than the bottom of any of the other Lakes except Lake Superior.

The Lake Ontario basin is a lowland bordered on the north by an escarpment of the Canadian Shield, on the east by the Adirondack Mountains, on the south by the Appalachian Plateau, and on the west by the Niagaran Escarpment. The Niagaran Escarpment is 200 feet high at Niagara Falls, but its height decreases as the escarpment stretches eastward, parallel to the south shore of Lake Ontario, until it becomes inconspicuous near Rochester, New York, approximately 70 miles from Niagara Falls.

Lake Ontario has a long east-west axis. The lake bottom slopes gradually southward from the north shore, across more than two-thirds of the Lake. The bottom formation then rises abruptly to the south shores.[15] During the ice ages, continental glaciers crossed the area and gouged out beds of soft shale to form the lake depression. The depth of scour and shape of the depression were influenced by hard limestone formations along the north shore of the Lake, extending over the sloping lake bottom nearly to the south shoreline. The retreating glaciers deposited sediments in the Lake and along its shoreline.

The Lake Ontario outflow is discharged into the St. Lawrence River at its northeast end.

2.8 St. Lawrence River

The St. Lawrence River is the natural outlet for the Great Lakes. It flows from Lake Ontario across the St. Lawrence Plain into the Gulf of St. Lawrence. This plain is a lowland between the Adirondack Mountains and the Canadian Shield. The broad, multiple-channel river head is broken into small land areas and is called the Thousand Islands Area. East of this area, the river channel narrows abruptly where it flows across a hard, resistant rock protrusion of the Canadian Shield. The river outlet is a long, horn-shaped passage which opens into the Gulf of St. Lawrence.

Marine waters of the Atlantic Ocean entered the ancient St. Lawrence River repeatedly during the Ice Age, and entered the Ontario basin at least once. Unusually high Atlantic tides reach across the Gulf of St. Lawrence and influence the St. Lawrence River water depths many miles inland.

Section 3

HYDROLOGY OF THE GREAT LAKES

3.1 General

The level of each of the Great Lakes depends upon the balance between the quantities of water received and the quantities of water removed. If these quantities are exactly the same, the general lake level is stable. If the quantities received are larger than the quantities removed, the volume of water in the Lake increases and the lake level rises. Supplies of water to, and removal of water from the Great Lakes are changing continually with natural hydrologic variations.

The vast water surface areas of the Great Lakes constitute a feature unique to the Great Lakes-St. Lawrence system. Small changes in the levels of the Lakes account for enormous quantities of water.

Large variations in supplies to the Lakes are absorbed and modulated to maintain outflows which are remarkably steady in comparison with the range of flows observed in other large rivers of the world. For example, a large monthly net supply of water to Lakes Michigan-Huron may be more than twice the dicharge capability of the St. Clair River. During such a month, at least one-half of the net supply would be added to water stored in the two Lakes. The resulting rise in the water surface during the month could be approximately four inches, with a corresponding increase in the discharge through the St. Clair River of three percent.

3.1.1 Relationship of Lake Levels and Outflows

Except where regulatory works have been provided to artifically control the individual lake levels, the level of a lake and its outflow bear a definite relationship to each other. When the lake level is above average, depth of water at its outlet is greater than average, and therefore the capacity of the outlet river to discharge must be above average. For any stage of a lake whose outflows are not artificially controlled, outflow rate is determined by the discharge capacity of the outlet river corresponding to that lake stage.

Under natural outlet conditions, as the supply of water changes, the lake level and outflow adjust continually to restore a balance between the net supply of water to the lake and the outflow from its natural outlet river. Outflows artificially controlled by regulatory works are released according to a plan for regulating the lake's levels and outflows.

Man-made modifications affecting the natural levels and flows of the Great Lakes, such as the regulation of Lakes Superior and Ontario and the diversions of water into and out of the Great Lakes Basin, are discussed in Section 6, Artificial Factors Affecting Lake Levels.

3.1.2 Lake Outflows

Table 11-4 indicates in cubic feet per second (cfs) the outflow of each of the Great Lakes through its natural outlet channel, including average, maximum, and minimum monthly outflows for the peroid of record.

In general, ice retards winter river discharges in the outlet channels, so winter outflow rates are somewhat less than corresponding open-water flows. The minimum monthly flows given for the St. Clair and the Niagara Rivers occurred under severe ice conditions. Monthly outflows are tabulated at the end of this appendix.

TABLE 11-4 Outflows of the Great Lakes in Cubic Feet per Second

Lake and Natural Outlet	Average 1860-1970	Maximum Monthly	Minimum Monthly
Superior, St. Marys River	75,000	127,100 (Aug. 1943)	40,900 (Sep. 1955)
Michigan, Straits of Mackinac	52,000	-------	-------
Huron, St. Clair River	187,300	242,000 (June 1886)	99,000 (Feb. 1942)
Erie, Niagara River	201,900	255,000 (June 1886)	116,000 (Feb. 1936)
Ontario, St. Lawrence River	239,200	314,000 (May 1870)	154,000 (Feb. 1936)

Water supplies to the Great Lakes consist principally of precipitation that falls on lake surfaces and runoff from land areas of the Basin. For each of the lower Lakes, the supply to the individual Lake's own basin is augmented by inflow of water from the Lake above. Total supply of any one of the Lakes is reduced by evaporation from that Lake's surface.

3.2 Reservoir Capacities

The huge natural reservoirs that are called the Great Lakes act exactly the same as reservoirs of any hydraulic system, but their size makes them unique. Lake levels at any time are a measure of the amounts of water stored at that time. Rises or recessions in lake levels from beginning to end of any time interval are a measure of the quantity of water added or removed during that interval. When the net supply to any one of the Lakes exceeds outflow, its level rises. When net supply is less than outflow its level falls. This is true whether the supplies and outflows are natural or modified artificially.

To comprehend the causes of variations of lake levels, or to comprehend the limitations and possibilities of regulating the levels, one must understand the interrelationships and proportions of the supplies of water to the reservoirs, their storage capacities, and the ability of their outlet rivers to discharge water. It is customary to consider these supplies and capacities in terms of some convenient time interval such as a month or a week. For many purposes, such as studies of lake regulation, monthly time intervals are convenient.

For example, one determines the net total supply to a lake by adding the outflow to the change in storage. The volumetric units generally used for outflow data are cfs-months and for change in storage plus or minus feet of lake surface. Before adding, one must express the terms in the same units. The relationship between the two units depends upon the number of seconds in the month considered, and the area of the lake involved.

Regulation studies computations use an average month of 30.4 days ($^{365}/_{12}$) for all months. The Lake area used is shown in Table 11-2. The equivalent feet on lake for 1,000 cfs-months and equivalent cfs-months for a change in storage of one foot are given in Table 11–5.

The values in the tabulation of Table 11–5 are independent of time. Thus a one-foot change in storage on Lake Ontario is 80,000 cfs-months, which is obtained with a flow of 80,000 cfs for one month, 40,000 cfs for two months, or 10,000 cfs for eight months. Relative reservoir capacity indicates that Lake Superior has 4.2 times the capacity of Lake Ontario, the smallest of the Great Lakes.

TABLE 11–5 Relationship Between Storage Volume and Depth in the Lakes

Lake	Feet on Lake for 1,000 cfs-months	CFS-Months for One Foot on Lake	Relative Reservoir Capacity
Superior	0.00296	337,800	4.2
Michigan-Huron	.00208	480,800	6.0
Erie	.00951	105,200	1.3
Ontario	.01250	80,000	1.0

3.2.1 Significance of Lake Regulation

The magnitude of the reservoir effect of Lakes Superior and Michigan-Huron is much greater than that of Lakes Erie and Ontario because it involves lake outlet capacity as well as lake storage capacity. The levels of Lakes Superior and Michigan-Huron respond to changes in outflow much more slowly than do the levels of Lakes Erie and Ontario. On the basis of difference in surface areas only, regulation of the levels of Lakes Superior and Michigan-Huron would require a greater range of flexibility in discretionary control of outflows than for Lakes Erie and Ontario to obtain a comparable degree of level stabilization. The occurrence of water supplies to the Lakes, also a factor in this regard, is discussed in Section 5.

Lake regulation involves control of outflows to accomplish a desired reduction in the range of stages experienced. Lake regulation studies require a knowledge of the reservoir effect of the lakes in its application under various sequences of supplies such as have occurred in the past. This in turn requires reliable analysis of past effects on a month-by-month basis. The next section discusses net total supplies which are used in such analyses.

3.2.2 Natural Regulation of the Great Lakes

Natural regulation of a lake exists when its outflows depend upon the lake levels and a stage-discharge relationship. In the Great Lakes, outflows from Lakes Superior and Ontario are fully controlled, and may vary widely at any water level.

The outflow from Lakes Michigan-Huron into Lake Erie depends basically on the levels of the upstream and downstream Lakes. The major outflow from Lake Erie goes down the Niagara River. The level of the upper Niagara

River is controlled only to meet Niagara Falls flow requirements, with the remainder diverted for power. The small flow in the Welland Canal is fully controlled. Therefore, a major portion of Lakes Michigan-Huron outflow depends on Lake Erie levels and a stage-discharge relationship. Stage-discharge relationships for uncontrolled outflow channels may be expressed in terms of lake level alone or lake level and slope in the river.

One must consider several varying natural conditions during certain periods in order for the relationship to be true. Ice retardation during the winter season is the difference between what the flow would have been under open-water conditions and the actual flow in the connecting rivers. It varies somewhat from year to year. In the past, severe ice-jamming has occasionally reduced the outflow from Lakes Michigan-Huron, raising its levels, while at the same time reducing inflow to Lake Erie and lowering it. During the summer weed retardation must be considered in estimating the connecting river flows.

3.3 Great Lakes Water Supplies

Total water supply is made up of inflow from the lake above, runoff from the drainage area surrounding the lake, direct precipitation over the lake surface, diversion into the lake from outside the drainage basin, and ground-water inflow. The total water withdrawn from the lake includes the outflow through the outlet channel, evaporation, diversion into another drainage basin, and seepage. The interrelation of these various factors may be expressed in the form of an equation as follows:

$$\Delta S = (I + R + P + Di + Gi) - (Q + E + Do + Go) \qquad (1)$$

where:

ΔS = change in lake storage due to rise or fall in level
I = inflow from lake above
R = runoff from drainage basin of lake
Di = diversion into lake from another basin
Gi = ground water inflow
P = precipitation on the lake
Q = outflow from lake
E = evaporation from lake
Do = diversion from lake into another basin
Go = seepage

All terms of the equation are in the same units and for the same period of time. This equation, sometimes called "The Equation of Hydrological Balance," applies with appropriate modification to each of the Great Lakes. For Lake Superior, the inflow term I is omitted since it is the uppermost in the system, and has no lake inflow. The diversion terms D and Di may be omitted for a lake of the system in situations where diversions are not pertinent.

From the definition and the relationship shown in Equation 1, two equations are available to determine the Total Water Supply (TWS) as follows:

$$\text{TWS} = I + R + P + Di + Gi \qquad (2)$$
$$\text{TWS} = \Delta S + Q + E + Do + Go \qquad (3)$$

where TWS = Total Water Supply for the period, and other terms are as used in Equation 1. The total water supply is very seldom determined because R and P in Equation 2 and E in Equation 3 are not readily available, and Gi and Go are not known.

One may measure a very useful supply quantity called the Net Total Supply (NTS) by subtracting the evaporation and seepage losses from the Total Water Supply. Using the defining and derived equations for the Total Water Supply above, two equations for Net Total Supply may be derived in terms of supply and withdrawal as follows:

$$\text{NTS} = I + R + P + Di + Gi - E - Go \qquad (4)$$

and,

$$\text{NTS} = \Delta S + Q + Do \qquad (5)$$

where NTS is the Net Total Supply and the other terms are the same as above.

The Net Total Supply includes water supplied from outside the drainage basin of the lake. The portion of the Net Total Supply contributed by the lake basin and lost from the lake is known as the Net Basin Supply (NBS). The quantities included in the Net Basin Supply are shown in a defining equation derived from Equation 4 as follows:

$$\text{NBS} = R + P + Gi - E - Go \qquad (6)$$

The quantity of Net Basin Supply is determined by an equation derived from Equation 5 as follows:

$$\text{NBS} = \Delta S + Q + Do - I - Di \qquad (7)$$

Little is known of the quantity of ground water entering or leaving the Great Lakes. The consensus of investigators using Equation 6 to estimate one or the other of the remaining factors is that the amount of water supplied through ground water is small when compared to runoff and precipitation, and the difference between inflow and outflow through the bottom is negligible. With this assumption Equation 6 may be rewritten as:

$$NBS = R + P - E \qquad (8)$$

Because numerous stations measure precipitation around the shores of the Great Lakes, it is possible to make a relatively accurate estimate of the monthly precipitation on the water surface of the Lakes. The Lake Survey Center has published these data for the Lakes since 1900. Insufficient data are available to estimate reliably the other two hydrological factors in Equation 8 to estimate monthly data.

Several investigators have determined the runoff from the land areas and evaporation from the lake surfaces on an average monthly basis for various periods of record. Since different periods of record were used in these studies, it is difficult to evaluate the various methods used by the investigators.

Many other secondary hydrologic factors affect the Net Basin Supply because of their effect on one or more of the primary factors in Equation 6. These secondary factors include such meteorological parameters as air temperature, wind speed, relative humidity, water temperature, and amount of sunshine.

Net water supply values are used in routing computations to determine the effects of specific regulation plans.

Section 4

LAKE LEVELS

4.1 General

Reliable records of the water levels for all of the Great Lakes date from 1860. The Lake Survey Center, National Ocean Survey, NOAA (formerly U.S. Army Engineer District, Lake Survey), maintains 50 permanent water level gages on the Great Lakes and along their outflow rivers.

Canadian agencies also maintain some water level gages on the Great Lakes system. The Canadian agency responsible for data is the Tides and Water Levels Division, Marine Sciences Branch, Department of Environment. Data from both Canadian and United States gages are often required for adequate consideration of Great Lakes problems, and the two countries exchange data freely. The water level gages listed in Table 11–6 are float-actuated recording instruments continously recording the water levels. Figure 11–3 shows the locations of these gages on the Lakes. Table 11–6 tabulates by gaging station the period of record available and extreme water level data recorded at these sites.

Water level records indicate that the entire surface of any one of the Great Lakes is seldom if every completely at rest. From beginning to end of any period there may be an appreciable change in the average level of the whole surface of a Lake that corresponds to a change in the volume of water in the Lake during that interval.

During any particular short time period, such as a few hours, the average level at one point on a Lake may be considerably above or below the average level at another point some distance from the first point. The differential would be caused by an external force, such as wind, acting on the lake surface. There are usually wind-generated waves of some magnitude at any point on the Lakes. The gravitational pull of the moon and sun, and water-temperature differentials disturb the lake surfaces very little.

Lake levels recorded at a particular gage station reflect the combined effect of all variations at that station except those due to wind-generated waves. The stilling well and inlet of the water level gages are proportioned to damp out such short-period waves.

The Great Lakes are considered essentially nontidal because fluctuations due to the gravitational effect of the moon and sun are relatively small and for any diurnal period other variations mask them. The gage records reflect the effect of lunar tides, however, as has been shown by averaging the readings for given stages in the passage of the moon over a time interval of several months.

Daily average (referred to as the daily mean) and monthly average (monthly mean) water levels are data that commonly help solve problems involving levels of the Great Lakes. The daily mean level at a gage is obtained by averaging the 24 hourly readings of the day; the monthly mean level is the average of the daily means for the days of the month. The monthly mean lake level as recorded by a representative gage for each Lake is published by Lake Survey Center (NOAA).

For certain purposes the mean level of a lake is determined as a whole by averaging for a given period, such as a month, the levels of several gages on the lake situated in a pattern selected to provide a good approximation of the whole lake level. Scientists have improved gage patterns in recent years, particularly for determinations of changes in lake storage. There is now a well-spaced pattern of at least five gages for each Lake. The monthly level change measured by a sufficient number of gages helps determine changes in amounts of water stored in each Lake.

Lake levels used in this appendix are in terms of the International Great Lakes Datum (1955), which gives elevations in feet above the mean water level at Father Point, Quebec, a point on the St. Lawrence River near the river's transition to the Gulf of St. Lawrence. This level datum provides dynamic elevations such that different points on the same Lake have the same elevation when the Lake is level, and it provides a hydraulically true representation of the river slopes.

Low water datum on each Lake is the water level to which depths on navigation charts and of harbor and channel improvements on the

TABLE 11-6 Great Lakes Water Level Gage Locations and Records

Lake	Gaging	Period of Gage Records		Extremes of Instantaneous Water Level Elevations, IGLD (1955)			
Lake	Station	Non-Recording	Recording	Maximum	Date	Minimum	Date
Superior	Duluth	1860-1950	1901-1969	602.89	31 Aug 1951	598.59	10 Jan 1958
	Grand Marais		1966-1969	602.59	28 Oct 1968	598.96	31 Mar 1967
	Marquette	1860-1909	1902-1969	604.06	16 Jun 1939	597.47	17 Jul 1926
	Michipicoten		1915-1969	604.28	16 Jun 1939	598.05	13 Apr 1926
	Ontonagon		1959-1969	603.66	17 Apr 1965	598.69	13 Apr 1964
	Point Iroquois		1930-1969	604.23	31 Oct 1951	598.48	21 Apr 1964
	Thunder Bay		1907-1969	603.17	21 Jul 1952	597.93	17 Mar 1926
	Two Harbors	1911-1937	1904-1969	603.53	5 May 1950	598.61	11 Apr 1948
Michigan	Calumet Harbor		1903-1969	583.19	25 Oct 1929	573.33	11 Nov 1940
	Green Bay		1953-1969	582.18	27 Jul 1969	573.17	21 Nov 1964
	Holland	1906-1908	1959-1969	580.65	28 Jul 1969	574.80	19 Dec 1964
	Ludington		1950-1969	580.95	4 Aug 1953	574.76	17 Jan 1965
	Mackinaw City[1]		1899-1969	582.01	22 Jul 1952	574.45	5 Mar 1964
	Milwaukee	1859-1903	1903-1969	581.89	22 Jul 1952	574.15	23 Jan 1926
	Port Inland		1963-1969	581.07	26 Jun 1969	574.19	18 Jan 1965
	Sturgeon Bay Canal	1905-1944	1945-1969	582.33	25 May 1953	574.10	14 Apr 1964
Huron	Collingwood		1906-1969	582.12	25 Jun 1952	573.48	26 Jun 1964
	De Tour	1944-1954	1954-1969	580.19	7 Aug 1969	574.26	5 Mar 1964
	Essexville	1884-1935	1952-1969	581.75	24 Oct 1953	571.54	18 Mar 1965
	Goderich		1910-1969	582.02	5 May 1952	574.26	28 Nov 1964
	Harbor Beach	1874-1901	1901-1969	582.01	6 May 1952	574.17	25 Jan 1964
	Harrisville		1963-1969	580.15	10 Aug 1969	574.36	9 Jan 1964
	Lakeport		1956-1969	580.76	Oct 1960	573.82	28 Nov 1964
	Little Current		1959-1969	580.48	7 Aug 1969	573.91	5 Mar 1964
	Mackinaw City[1]		1899-1969	582.01	22 Jul 1952	574.45	5 Mar 1965
	Parry Sound		1960-1969	580.44	8 Aug 1969	573.63	26 Mar 1964
	Thessalon		1926-1969	581.68	23 Jul 1952	574.37	12 Feb 1965
	Tobermory		1962-1969	580.84	26 Jun 1969	574.30	24 Jan 1965
St. Clair	Grosse Pte. Shores	1894-1952	1955-1969	575.51	8 Jul 1969	569.58	26 Jun 1964
Erie	Barcelona	1958	1960-1969	574.82	27 Oct 1967	565.08	10 Mar 1964
	Buffalo	1819-1899	1889-1969	579.09	3 Nov 1955	564.17	10 Mar 1964
	Cleveland	1838-1903	1903-1969	574.03	29 Jun 1952	565.71	4 Feb 1936
	Erie	1859-1903	1957-1969	574.14	14 Dec 1968	566.00	10 Mar 1964
	Erieau		1957-1969	573.02	4 Jul 1969	566.85	21 Nov 1964
	Fermi		1962-1969	573.95	27 Apr 1966	563.03	16 Feb 1967
	Kingsville		1961-1969	573.54	27 Jul 1969	564.13	21 Nov 1964
	Marblehead		1959-1969	573.62	18 Apr 1969	564.54	21 Nov 1964
	Port Colborne	1860-1911	1911-1969	577.69	1 Apr 1929	564.22	10 Mar 1964
	Port Dover		1958-1969	575.80	27 Oct 1967	565.02	10 Mar 1964
	Port Stanley		1908-1969	574.17	22 Mar 1955	566.58	17 Mar 1935
	Sturgeon Point		1968-1969	575.18	9 May 1969	568.70	31 Dec 1969
	Toledo	1911-1939	1940-1969	575.67	27 Apr 1966	561.47	2 Jan 1942
Ontario	Cape Vincent	1936-1954	1914-1969	248.10	16 May 1929	240.93	2 Jan 1965
	Cobourg		1956-1969	247.66	2 Jul 1956	241.26	25 Dec 1964
	Hamilton		1960-1969	246.45	3 Jun 1969	241.04	3 Feb 1965
	Kingston	1895-1910	1910-1969	248.55	6 Jun 1952	241.01	2 Jan 1965
	Olcott	1935-1958	1967-1969	246.40	20 Jun 1969	243.26	19 Nov 1969
	Oswego	1837-1932	1933-1969	248.96	6 Jun 1952	240.94	23 Dec 1934
	Port Weller		1929-1969	247.85	30 May 1930	241.19	3 Feb 1965
	Rochester	1846-1907	1952-1969	246.95	23 May 1956	241.38	23 Dec 1964
	Toronto	1861-1916	1916-1969	248.34	8 Jun 1952	240.64	26 Dec 1964

[1]Common gage at Straits of Mackinac

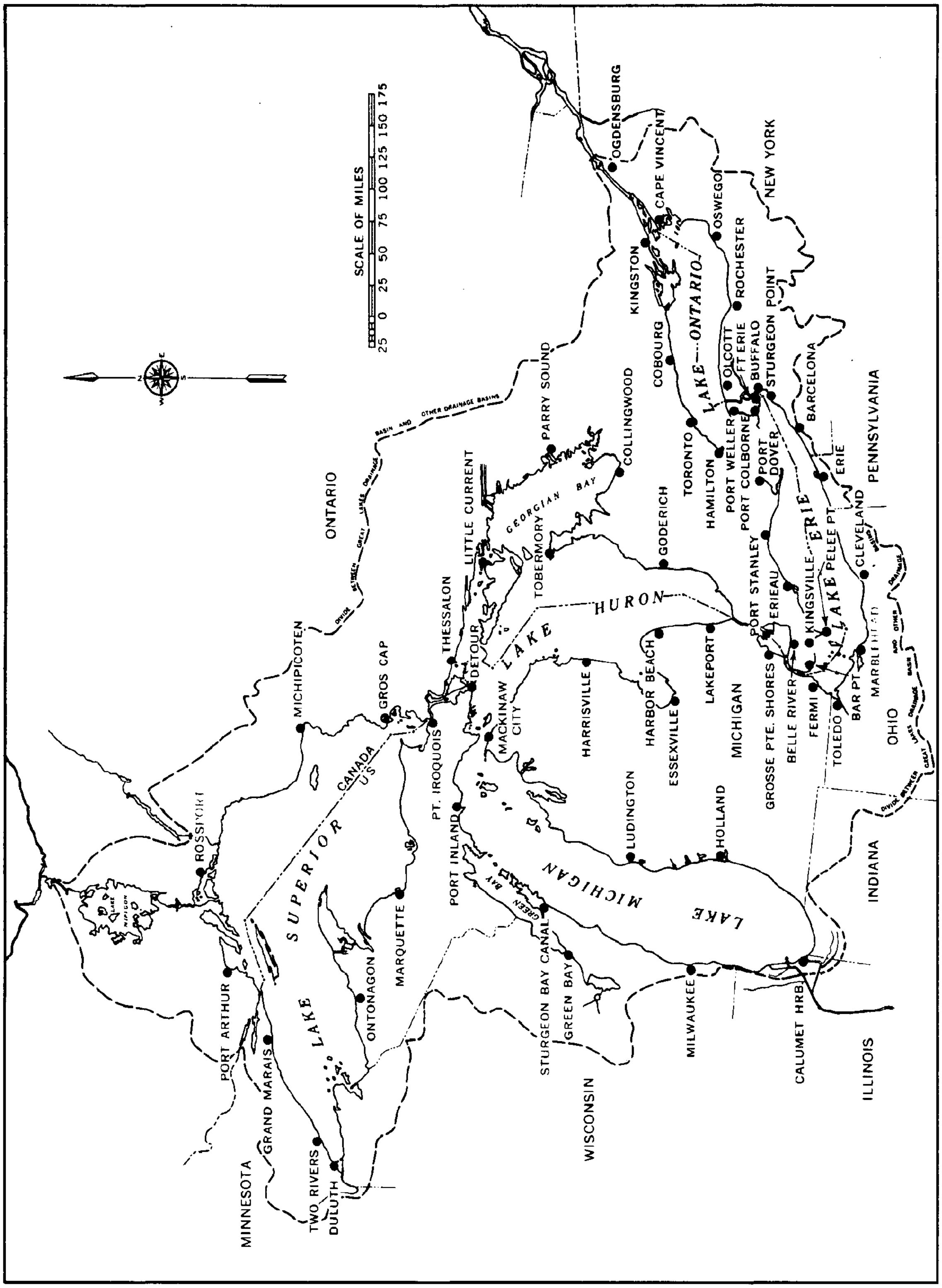


FIGURE 11–3 Water Level Gaging Stations on the Great Lakes

TABLE 11–7 Water-Level Gage Records

Gaging Station	Period of Record
St. Marys River	
U.S. Slip*	1903-1971
SW Pier*	1867-1971
St. Clair River	
Algonac	1952-1971
St. Clair	1951-1971
Marysville	1953-1971
Dry Dock	1919-1971
Mouth Black River	1952-1971
Dunn Paper	1955-1971
Fort Gratiot	1937-1971
Detroit River	
Gibraltar	1937-1971
Wyandotte	1946-1971
Fort Wayne	1905-1971
Windmill Point	1897-1971
Niagara River	
Ashland Avenue	1957-1971
American Falls	1955-1971
Niagara Intake	1962-1971
La Salle*	1965-1971
Tonawanda Island*	1930-1971
Huntley Station*	1930-1971
Blake Rock*	1932-1971
Peace Bridge*	1967-1971
St. Lawrence River	
Ogdensburg	1934-1971
Cape Vincent	1916-1971

*Corps of Engineers, Detroit District Gages

Great Lakes are referred. The elevations on IGLD (1955) of the low water datum lake levels are in Table 11–12 later in this section. For the outlet rivers, low water datum is the sloping surface of the rivers when the Lakes are at their low water datum elevations.

4.2 Water Level Gage Records on the Outflow Rivers of the Great Lakes

The Lake Survey Center, NOAA, maintains permanent water level gages on the outflow rivers of the Great Lakes. The location of these gages and the records available are shown in Table 11–7.

4.2.1 Canadian Gages on Outflow Rivers

The Canadian agency, Tides and Water Levels Division, also maintains gages on the Great Lakes outflow rivers. Gage locations and other pertinent information are given in Table 11–9.

4.2.2 Niagara River Power Project Gages

The Hydro Electric Power Commission of Ontario operates five gages on the Canadian side of the Niagara River in connection with the Niagara River Power Project. The location of these gages and the records available are shown in Table 11–8.

4.2.3 St. Lawrence River Power Project Gages

The Hydro Electric Power Commission of Ontario and the Power Authority of the State of New York operate 16 gages on the St. Lawrence River in connection with the St. Lawrence River Power Project. The location or designation of 15 of these gages and the records available are provided in Table 11–10.

4.3 Reference Planes

Reference planes on the Lakes and connecting rivers provide a basis for preparation of navigation charts and for dredging and construction.

4.3.1 Historical Background

The first plane of reference for each of the Great Lakes was known as the "High Water of

TABLE 11–8 Niagara River Power Project Gages

Gage	Record Yrs.
Fort Erie	1958-1971
Frenchman's Creek	1958-1971
Black Creek	1965-1971
Slaters Point	1919-1971
Material Dock	1921-1971

TABLE 11-9 Canadian Gage Information

Gage Location	Period of Record	Extreme of Instantaneous Water Level			
		Maximum	Date	Minimum	Date
St. Marys River					
Gros Cap	1926-1971	602.58	22 Oct 1968	598.00	25 Jan 1968
Rossport	1967-1971	602.96	30 Jun 1968	598.75	31 Mar 1967
Sault St. Marie Lock Above	1908-1971	604.09	12 Nov 1942	596.48	23 May 1925
Sault St. Marie Lock Below	1908-1971	584.83	17 Dec 1951	575.78	23 Nov 1963
St. Clair River					
Point Edward	1927-1971	581.41	5 May 1952	573.06	28 Nov 1964
Point Lambton	1927-1971	577.51	29 Jan 1952	571.55	27 Nov 1964
Lake St. Clair					
Belle River	1961-1971	576.03	4 Jul 1969	569.34	5 Mar 1964
Detroit					
Tecumseh	1926-1971	575.97	1 Jul 1952	568.92	13 Jan 1936
La Salle	1925-1971	575.19	22 Mar 1952	568.24	28 Jun 1926
Amherstburg	1960-1971	573.37	6 Jul 1969	566.21	27 Jan 1965
Bar Point	1966-1971	573.37	18 Apr 1969	566.76	5 Dec 1968
Lake Erie					
Pelee Point	1964-1971	573.03	25 Jun 1968	565.07	21 Nov 1964
St. Lawrence River					
Long Sault	1962-1971	243.41	9 May 1964	235.31	15 Jan 1968
Prescott	1919-1971	243.12	12 May 1952	239.85	4 Dec 1964
Iroquois Lock Above	1959-1971	245.18	14 May 1963	237.49	2 Feb 1963
Iroquois Lock Below	1959-1971	243.35	4 May 1962	236.79	1 Feb 1963

1838." The original planes were satisfactory for referencing water levels, but were too high for construction and charting purposes. As a result, engineers established a number of other reference planes for various purposes throughout the years.[38]

By 1930 it was obvious from the increasing differences in water surface elevations as recorded at the various harbors that a reevaluation of benchmark elevations was necessary. In 1935 many additional water level gages were installed, thereby providing data for water-level transfers to almost every U.S. harbor on the Great Lakes. New level lines had been run between the Lakes to determine the differences in elevation between them. However, no new instrument level connection to sea level had been made at that time. Existing elevation on each Lake was based on the 1903 adjustment with respect to sea level at New York and adopted as 1935 Datum.

In 1953, the U.S. Lake Survey Center and

TABLE 11-10 St. Lawrence River Power Gages

Gage	Record Yrs
Chimney Point	1954-1971
H-24-CA	1954-1971
D CA	1954-1971
Iroquois Dam Headwater	1958-1971
Iroquois Dam Tailwater	1958-1971
Waddington	1958-1971
Morrisburg	1958-1971
Long Sault Dam Headwater	1958-1971
Moses Power Dam Headwater	1958-1971
Saunders G. Station Headwater	1958-1971
International Tailwater	1959-1971
Moses Power Dam Tailwater	1958-1971
H-26-CA	1954-1971
H-8-CA	1954-1971
H-21-CA	1954-1971

the Canadian Hydrographic Service began coordinating basic hydraulic and hydrologic data on the Great Lakes. At this time Canadian reference datums differed from those of the United States. They had different reference zeros, and as a result the lake levels as published by agencies of the two governments were not identical.

These differences in levels and other data were considered insignificant until the advent of the St. Lawrence Seaway and international power development on the St. Lawrence River. Then it became very important that basic hydraulic and hydrologic data pertaining to the Great Lakes system be the same in both countries.

4.3.2 International Great Lakes Datum (1955)

In establishing this new international datum, certain basic criteria had to be met:

(1) The datum had to be acceptable to both governments.

(2) It had to include an adjustment of all elevations to correct changes caused by crustal movement.

(3) It had to correct any past errors in earlier surveys.

(4) It had to provide elevation suitable for use in resolving the many complex hydraulic and hydrologic problems in the Great Lakes system.

Father Point, Quebec, was chosen as the site of the new reference of zero elevation for the following reasons:

(1) It is the outlet of the Great Lakes-St. Lawrence River system.

(2) The mean water level there is approximately equal to mean sea level.

(3) The water level gage at Father Point has a long record.

(4) Benchmarks at this site are connected to the rest of the system by first-order levels.[9]

International Great Lakes Datum (1955) was established along the St. Lawrence River by first-order levels from Father Point to Kingston, Ontario, at the eastern end of Lake Ontario. A parallel line which connected at several common points was completed along the United States side of the St. Lawrence River. The new datum was extended to the upper Lakes by first-order level lines along the connecting rivers coupled with water-level transfers across the Lakes. More than 1,200 miles of first-order levels and many gage records had to be used to determine elevations on the new international datum. When a new datum is established, it brings the elevations of all benchmarks in the system into harmony; that is, the assigned elevations measure their respective places in direct relation (either above or below) to the new single benchmark.

Because of crustal movement, which is discussed in detail in Section 5, it becomes very important to show the year in which the elevations were assigned. Internationally coordinated plans are under way (1967–1973) to reevaluate the elevations of all benchmarks and a new adjustment may be made. Revised elevations may be published in the future as International Great Lakes Datum (1970).

4.3.3 Other Commonly Used Datum Planes as Compared with IGLD (1955)

Several other reference datum planes are commonly used in the Great Lakes Basin. The most common are described below.

4.3.4 Sea Level Datum of 1929

The U.S. Geological Survey, in establishing vertical control for producing topographic maps, uses the national network of benchmarks established by the U.S. Coast and Geodetic Survey (USC&GS), whose functions have been included under the National Ocean Survey. Elevations of the national network are on Sea Level Datum of 1929 and have been adjusted to account for the non-parallelism of level surfaces related to the flattening of the earth at its poles. Because of the orthometric correction and other factors such as instability of the benchmarks, the differences between IGLD (1955) and Sea Level Datum of 1929 elevations vary from place to place.

Because of the many variables, the two datums at a specific location must be compared by instrumental levels. The Lake Survey Center accomplished this by leveling to U.S. Geological Survey (USGS) or USC&GS benchmarks at various Great Lakes harbors and along the connecting rivers.

Any local rise or settlement that might have occurred in a particular benchmark during the interval of time between the levels of the USC&GS, Lake Survey Center, and the USGS would be included in the difference between the elevations shown. Therefore, one must apply with caution a computed difference for one benchmark to convert other marks from one datum to another so that each datum becomes consistent.

TABLE 11-11 Conversion Factor for Various Locations on the Great Lakes—Difference in Elevations on IGLD (1955) and U.S. Coast and Geodetic Survey Datum

Location	Factor	Lake or Connecting River	Location	Factor	Lake or Connecting River
Michigan			New York		
Monroe	1.46	Lake Erie	Alexandria Bay	0.95	St. Lawrence River
Gibraltar	1.43	Detroit River	Clayton	1.09	St. Lawrence River
Trenton	1.43	Detroit River	Cape Vincent	1.10	St. Lawrence River
Grosse Ile	1.45	Detroit River	Oswego	1.22	Lake Ontario
Wyandotte	1.40	Detroit River	*Sodus Bay	1.31	Lake Ontario
Ecorse	1.39	Detroit River	*Rochester	1.22	Lake Ontario
River Rouge	1.39	Detroit River	Olcott	1.15	Lake Ontario
Detroit	1.36	Detroit River	Wilson	1.13	Lake Ontario
*Port Huron	1.17	Lake Huron	Fort Niagara	1.12	Lake Ontario
*Port Austin	1.24	Lake Huron	Stella Niagara	1.12	Niagara River
*Bay City	1.46	Lake Huron	Buffalo	1.29	Lake Erie
*Saginaw	1.40	Lake Huron	*Dunkirk	1.45	Lake Erie
*Harrisville	1.48	Lake Huron			
Alpena	1.16	Lake Huron	Wisconsin		
Mackinaw City	0.94	Straits of Mackinaw	Milwaukee	1.30	Lake Michigan
*Leland	1.24	Lake Michigan	Green Bay	1.23	Lake Michigan
*Muskegon	1.43	Lake Michigan	Port Washington	1.22	Lake Michigan
*St. Joseph	1.56	Lake Michigan	*Algoma	1.20	Lake Michigan
Escanaba	1.03	Lake Michigan	*Ashland	1.26	Lake Superior
Manistique	0.96	Lake Michigan			
*St. Ignace	0.95	Straits of Mackinaw	Minnesota		
De Tour	0.84	Lake Huron	Duluth	1.21	Lake Superior
Stalwart	0.74	St. Marys River			
Barbeau	0.76	St. Marys River	Indiana		
Sault Ste. Marie	0.71	St. Marys River	Indiana Harbor	1.45	Lake Michigan
Brimley	0.76	St. Marys River			
Pt. Iroquois	0.74	Lake Superior	Pennsylvania		
Marquette	0.96	Lake Superior	Erie	1.47	Lake Erie
Houghton	1.21	Lake Superior			
			Ohio		
New York			Cleveland	1.57	Lake Erie
Massena	0.75	St. Lawrence River	*Vermilion	1.62	Lake Erie
Waddington	0.78	St. Lawrence River	Toledo	1.45	Lake Erie
Ogdensburg	0.79	St. Lawrence River			
Morristown	0.83	St. Lawrence River	Illinois		
Chippewa Bay	0.87	St. Lawrence River	Chicago	1.30	Lake Michigan

*Factor based on only one benchmark

NOTE: In each case the figure in feet is subtracted from the U.S. Coast and Geodetic Survery elevation to obtain the elevation on IGLD (1955).

Table 11-11 provides a mean value differential to convert an elevation referenced to Mean Sea Level of 1929 datum (USC&GS) to an elevation on IGLD (1955). Unless otherwise noted, the conversion factor provided for each location is based on known differences in two or more benchmarks.

4.3.5 Chicago City Datum Plane

The following relationship has been determined: zero elevation Chicago City Datum equals 578.18 feet IGLD (1955). Also, zero elevation Chicago City Datum equals 579.48 feet USC&GS.

4.3.6 Detroit City Datum Plane

Zero elevation Detroit City Datum equals 478.45 feet IGLD (1955).

4.3.7 Cleveland City Datum Plane

Zero elevation Cleveland City Datum equals 573.27 feet IGLD (1955).

4.3.8 Buffalo City Datum Plane

Zero elevation Buffalo City Datum equals 574.28 feet IGLD (1955).

4.3.9 Milwaukee City Datum Plane

Based on comparison of elevations of eight benchmarks, the following relationship has been determined: zero elevation Milwaukee City Datum equals 579.30 feet IGLD (1955).

4.3.10 Low Water Datum

The 1935 datum plane was used prior to the establishment of International Great Lakes Datum (1955) and was in use until 1961. The Low Water Datum planes of reference for the Great Lakes, the planes to which navigation improvement depths and Great Lakes navigation chart depths are referred, were not physically changed at that time. However, as the reference benchmarks at all harbors on the Great Lakes were assigned an elevation on IGLD (1955), the elevation of the Low Water Datum on each Lake was changed also. Table 11–12 shows the 1935 Datum elevation and IGLD (1955) elevation for each Lake's Low Water Datum plane of reference.

TABLE 11–12 Elevations of Low Water Datum Reference Planes

Lake	1935 Datum	IGLD (1955)
Superior	601.6	600.0
Michigan	578.5	576.8
Huron	578.5	576.8
St. Clair	573.5	571.7
Erie	570.5	568.6
Ontario	244.0	242.8

4.4 Lake Level Variations

For the purposes of this study, variations of Great Lakes levels are classified as long-period variations, those with general trends upward or downward extending over several years; seasonal variations, representing an annually recurring cycle; and short-period variations, lasting from several minutes to a day or two. The first two classes relate to the changes in the volume of water in the Lake.

The third class consists of variations that may occur at any lake stage, and that involve temporary and frequently rapid changes in level in any one area of the Lake. These changes are local in nature and differ from place to place around the Lake. A hydrograph of monthly levels recorded at particular locations on each of the Great Lakes since 1860 and on Lake St. Clair since 1898 is available later in this section. This hydrograph illustrates the seasonal and long-period variations, but does not show short-period variations.

4.4.1 Long-Period Variations

Long-period variations of lake levels are associated with cumulative departures from normal hydrologic factors, principally precipitation falling on the Lake basins. For periods when there is a prolonged upward trend in Lake levels from near average level, the rainfall records show above normal precipitation amounts. When there is a prolonged downward trend from near average level, the records show below normal precipitation. Frequently, but not always, high water periods or low water periods occur on all of the Lakes concurrently. Excess or deficiency of precipitation over the basin of one of the Lakes may differ materially from that over the other basins.

Water supplies to the Great Lakes during 1965–1967 were sufficient to remedy the low water conditions on the Lakes in 1964. Hydrographs, Figures 11–4 and 11–5, show improvements in lake levels from 1964 to 1967.

The levels-and-flows pattern in the Great Lakes system is complicated. Seasonal fluctuations in annual weather patterns, when superimposed on the 1964–1967 trend, depict variations between below normal and above normal precipitation. Figure 11–6 shows variations for Lakes Michigan-Huron. The uppermost line in the figure represents the accumulated deviations of monthly precipitation from average values. For periods when the line is rising, the precipitation is above normal. When it is horizontal, the precipitation is normal. When it is falling, the precipitation is below normal. The solid middle line in the figure represents the accumulated monthly deviations of the net total supplies to the Lake. The solid line near the bottom of the figure shows the monthly Lakes Michigan-Huron water levels which occurred during the 1957 to 1965 period. The dashed line represents the long-term average monthly levels. The difference between the two bottom lines therefore represents the deviation from the long-term levels.

The similarity in pattern of the three solid lines shows the effects of extended above or below normal precipitation. Net total supplies to the Lake are reflected in corresponding large water-level deviations. However, other factors also affect water levels. The effects of other factors on lake levels are discussed in Sections 5 and 6.

A monthly water-level bulletin showing recorded levels of the Great Lakes for previous years, current year to date, and probable levels for the next six months is published by the Lake Survey Center.

The time intervals between successive high water periods, or between successive low water periods, are irregular. Rises and recessions may be gradual or abrupt. A number of attempts have been made to find periodic cycles in long-term rise and fall of the lake levels. When found, efforts will be made to correlate them with cycles of such phenomena as sunspots. Cycles as short as seven years, and as long as 90 years have been suggested. Statistical analysis of the levels and planetary movements do not support such theories.

4.4.2 Seasonal Variations

An annual pattern of seasonal fluctuation of monthly mean levels between a high in the summer and a low in the winter occurs on each of the Great Lakes. Variations between highs and lows, as well as the months in which they occur, may differ considerably from year to year. Seasonal patterns in the natural hydrologic factors cause these fluctuations.

In the spring, runoff increases because of snowmelt and decreased evapotranspiration. Evaporation from lake surfaces is slight during the spring. As a result, the lake level begins to rise.

In the summer, runoff is less because snowmelt does not occur, evapotranspiration losses are large, and evaporation from lake surfaces begins to increase. As a result, lake levels begin to decline from their peak.

In the fall, evapotranspiration is less, and runoff is again reduced, but surface evaporation is at a maximum. The onset of freezing temperatures keeps runoff low. The Lakes generally reach their lowest annual levels during the winter. These factors are described in detail in Section 5.

Lake Superior often reaches its seasonal low in March and its high in August or September. Lakes Michigan-Huron often are at their low in February and their seasonal high in July. Lake Erie attains its seasonal low in February and its high in June. The low on Lake Ontario usually occurs in January, and the seasonal high occurs most frequently in June. Table 11–2 lists the average rise from winter to summer high level for each Lake and the maximum and minimum intervals of rise in levels.

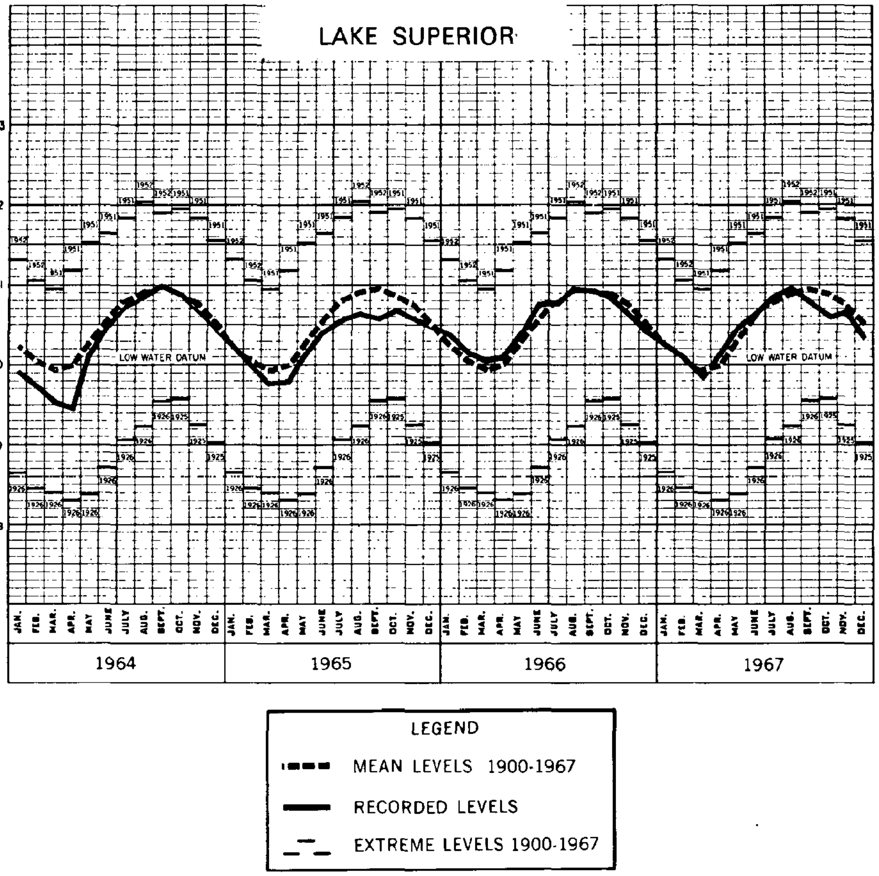
4.4.3 Short-Period Variations

At any point on the Great Lakes there are daily and hourly fluctuations in levels from a few inches to several feet. These fluctuations, independent of the volume of water in a Lake, are caused by winds blowing over a Lake's surface or differences in atmospheric pressure on different areas.

During such short-period disturbances, the level of one area of the Lake rises while the level of another area drops. For example, the wind in causing such a disturbance may drive the surface water forward in greater volume than that carried by the lower return currents, thus raising water level at the shore toward which the wind is blowing and lowering it at the opposite shore. Such effects are more pronounced in bays and the extremities of the Lakes where converging shores concentrate the water in a restricted space. Maximum short-period rises and falls that have been recorded at various gage sites on the individual Lakes and their frequencies of occurrence are shown on Table 11–37 in Section 8.

Waves disturb the lake surfaces. During severe storms over the Great Lakes, waves in deepwater areas may have heights greater than 20 feet from crest to trough. Such deepwater waves get much smaller as they move

(Continued on page 34)



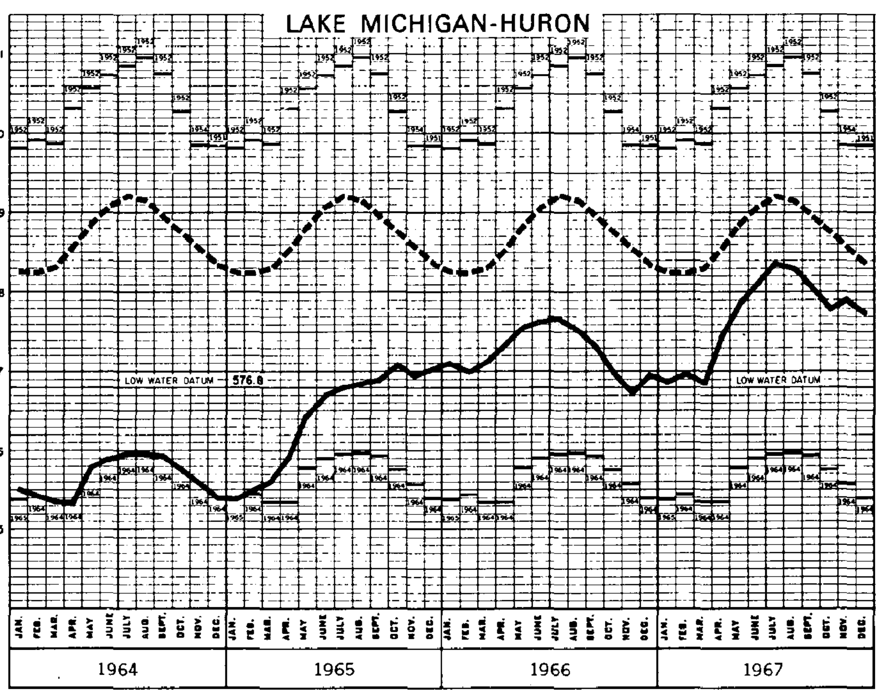


FIGURE 11–4 Hydrographs of Great Lakes Water Levels 1964–1967

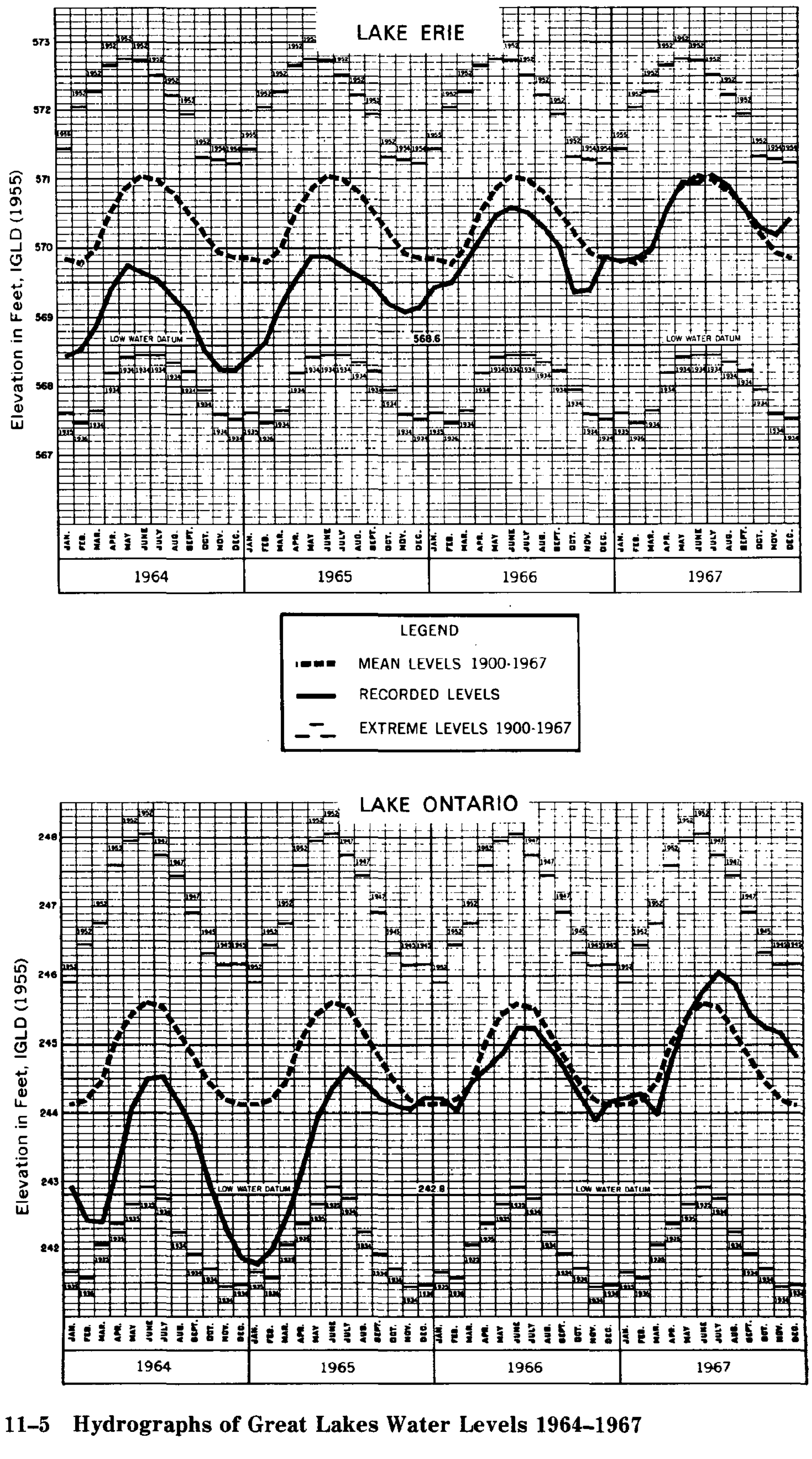


FIGURE 11–5 Hydrographs of Great Lakes Water Levels 1964–1967

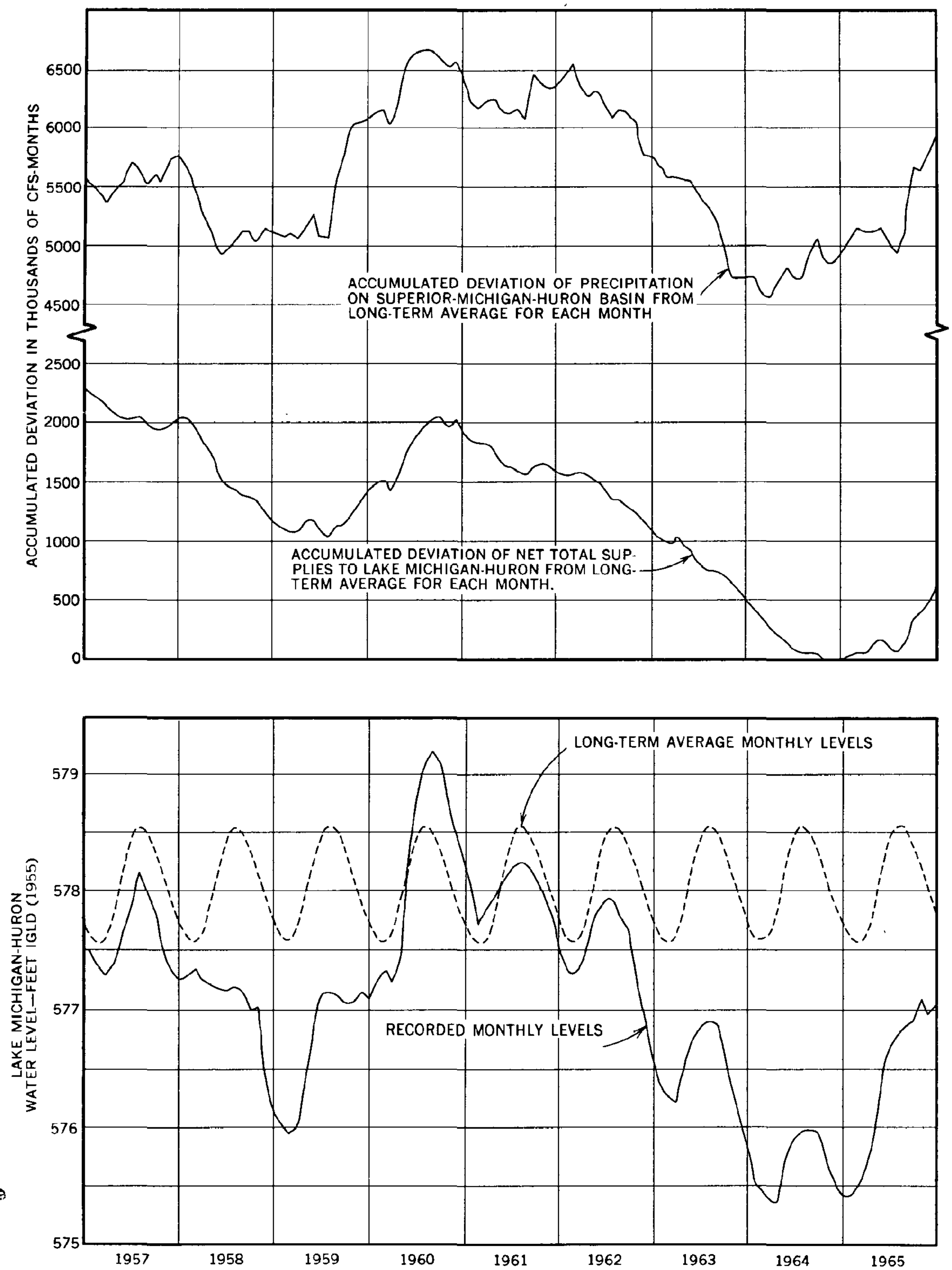


FIGURE 11–6 Effect of Precipitation and Net Total Water Supplies on Water Levels of Lakes Michigan-Huron

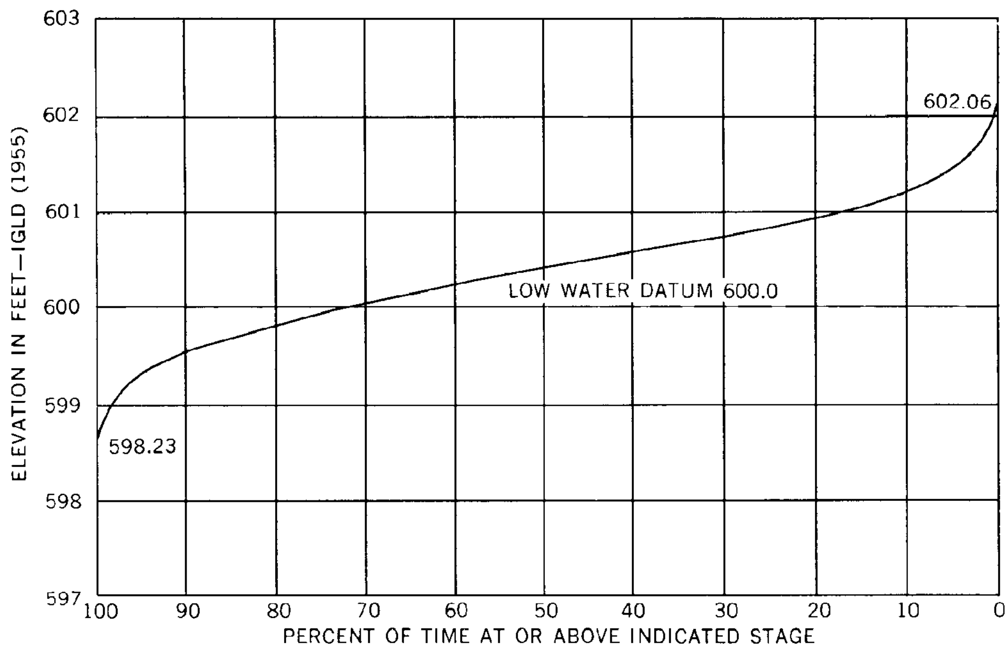


FIGURE 11–7 Lake Superior at Marquette—Stage Duration Curve for January-December 1860–1968

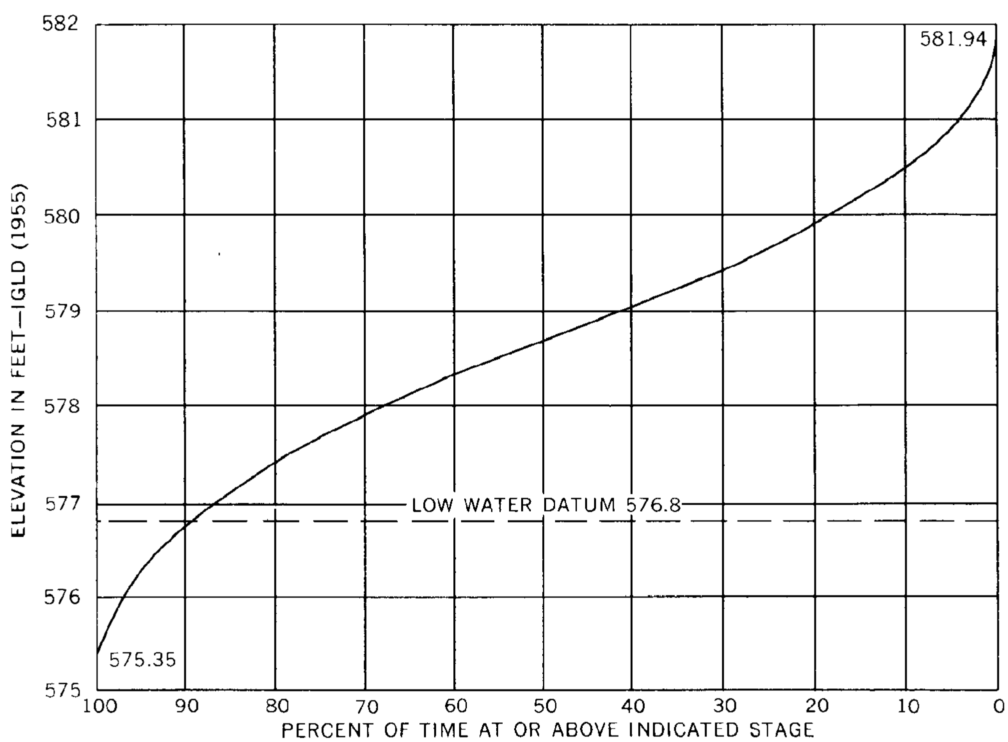


FIGURE 11–8 Lakes Michigan-Huron at Harbor Beach—Stage Duration Curve for January-December 1860–1968

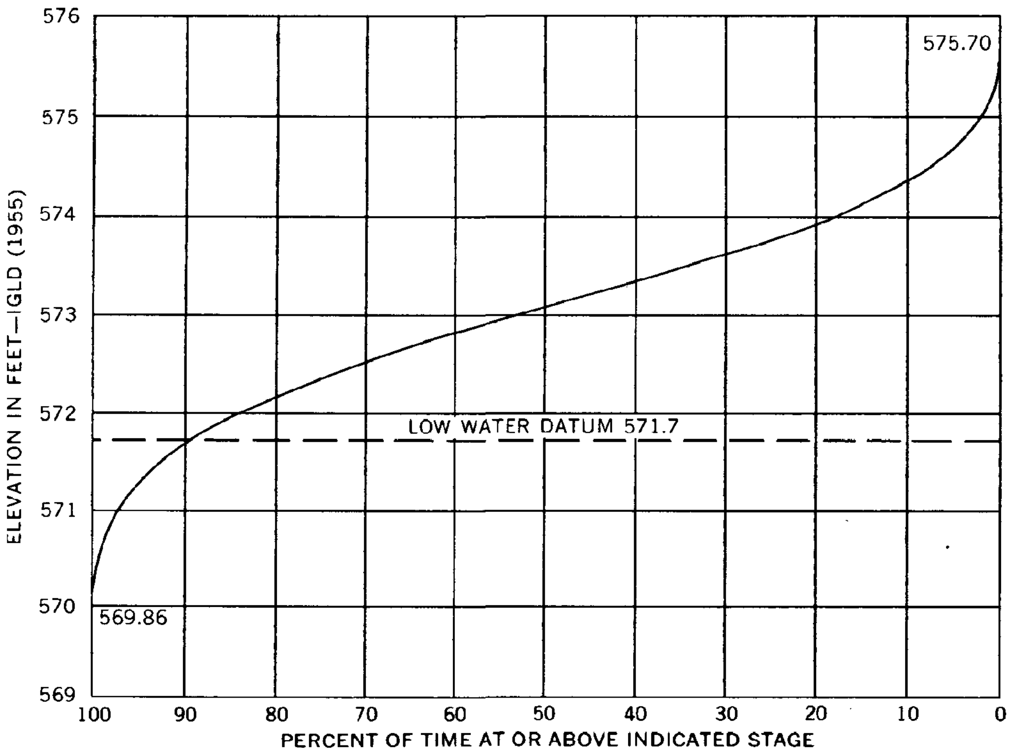


FIGURE 11-9 Lake St. Clair at Grosse Pointe—Stage Duration Curve for January-December 1860-1968

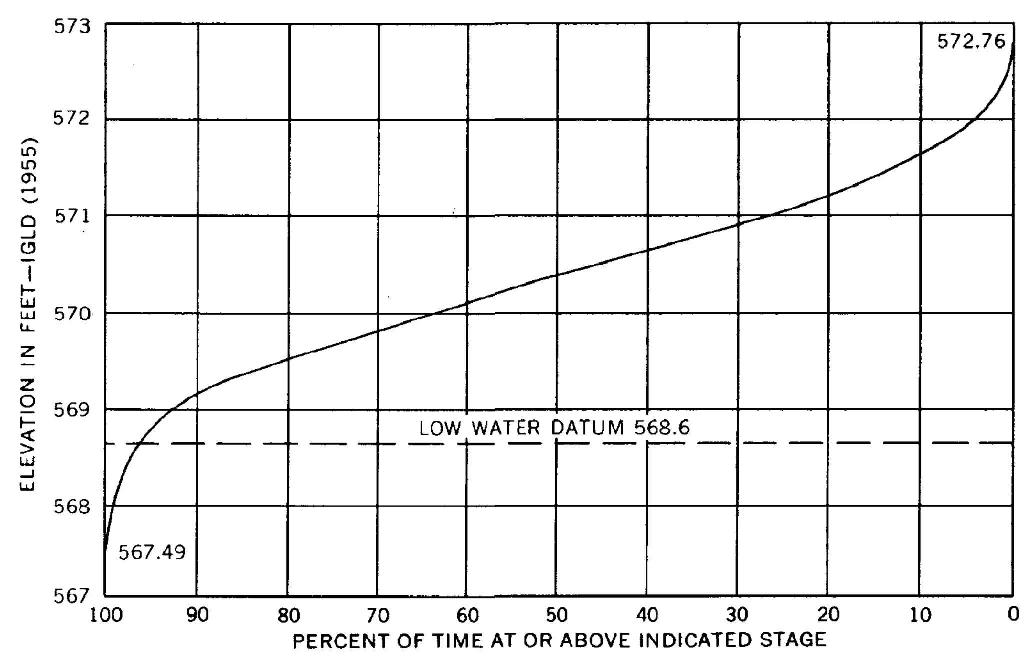


FIGURE 11-10 Lake Erie at Cleveland—Stage Duration Curve for January-December 1860-1968

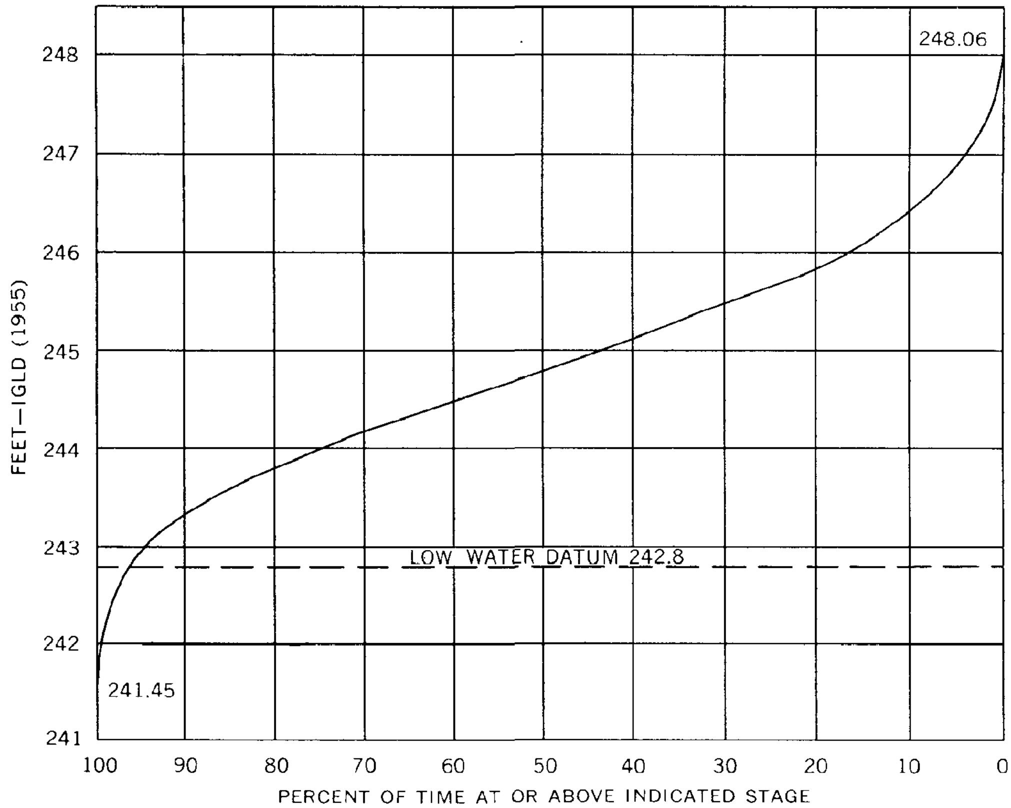


FIGURE 11–11 Lake Ontario at Oswego—Stage Duration Curve for January-December 1860–1968

TABLE 11–13 Lake Superior Water Level Data at Marquette, Michigan

Stages (feet above sea level)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	1952 601.28	1952 601.04	1951 600.91	1951 601.14	1951 601.53	1950–51 601.64	1876 601.95	1876 602.06	1876 601.95	1951 601.93	1951 601.77	1951 601.50
Low	1926 598.58	1926 598.37	1926 598.32	1926 598.23	1926 598.30	1926 598.63	1926 598.99	1926 599.15	1926 599.46	1864 599.47	1925 599.17	1925 598.94
Mean	600.112	599.916	599.809	599.856	600.192	600.483	600.693	600.799	600.833	600.778	600.628	600.379
Changes (in feet)	**Jan-Feb**	**Feb-Mar**	**Mar-Apr**	**Apr-May**	**May-Jun**	**Jun-Jul**	**Jul-Aug**	**Aug-Sep**	**Sep-Oct**	**Oct-Nov**	**Nov-Dec**	**Dec-Jan**
Maximum Rise	1867 +0.26	1871 +0.42	1869 +0.58	1894 +0.78	1880 +0.80	1952 +0.49	1911 +0.47	1900 +0.52	1941 +0.35	1915 +0.10	1864 +0.11	1878–79 +0.03
Maximum Fall	1871 -0.60	1878 -0.77	1879 -0.39	1879 -0.36	1867 -0.09	1861 -0.08	1878 -0.12	1954 -0.23	1952 -0.47	1865[a] -0.48	1870 -0.93	1868–69 -0.52
Average	-0.196	-0.107	+0.048	+0.335	+0.291	+0.210	+0.106	+0.034	-0.054	-0.150	-0.249	-0.254

Average 1860–1968: 600.374 feet above sea level
Average 1900–1968: 600.518 feet above sea level

[a]Also occurred in 1952

TABLE 11–14 Lakes Michigan-Huron Water Level Data at Harbor Beach, Michigan

Stages (feet above sea level)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	1860 580.94	1860 581.12	1860 581.15	1886 581.42	1886 581.75	1886 581.94	1876 581.86	1876 581.80	1876 581.69	1861 581.36	1876 581.14	1861 580.96
Low	1965 575.39	1964 575.44	1964 575.35	1964 575.36	1964 575.79	1964 575.90	1964 575.96	1964 575.97	1964 575.94	1964 575.77	1964 575.57	1964 575.40
Mean	578.245	578.222	578.292	578.521	578.828	579.061	579.196	579.144	578.967	578.750	578.537	578.349

Changes (in feet)	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan
Maximum Rise	1881 +0.39	1868 +0.68	1929 +0.70	1960 +0.83	1943 +0.68	1883 +0.48	1869 +0.26	1870 +0.14	1881 +0.25	1928 +0.16	1934 +0.23	1884–85 +0.27
Maximum Fall	1961 -0.25	1869 -0.26	1915 -0.12	1946 -0.04	1891 -0.05	1886 -0.26	1868 -0.34	1871 -0.67	1871 -0.69	1865 -0.56	1872 -0.66	1943–44 -0.39
Average	-0.026	+0.069	+0.229	+0.307	+0.233	+0.134	-0.052	-0.177	-0.217	-0.213	-0.189	-0.130

Average 1860–1968: 578.676
Average 1900–1968: 578.018

TABLE 11–15 Lake St. Clair Water Level Data at Grosse Pointe, Michigan

Stages (feet above sea level)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	1952 575.13	1952 574.87	1952 575.19	1952 575.46	1952 575.49	1952 575.60	1952 575.70	1952 575.65	1952 575.41	1952 574.87	1954 574.60	1951 574.83
Low	1936 569.86	1926 569.88	1934 570.41	1901 571.09	1934 571.64	1934 571.74	1934 571.88	1934 571.60	1934 571.36	1934 571.13	1934 570.83	1925 571.05
Mean	572.339	572.014	572.487	573.110	573.419	573.608	573.681	573.566	573.341	573.065	572.766	572.768

Changes (in feet)	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan
Maximum Rise	1939 +0.83	1956 +1.79	1913 +1.53	1901 +1.29	1901 +0.81	1902 +0.62	1915 +0.22	1912 +0.08	1954 +0.28	1898 +0.01	1914 +0.63	1915–16 +0.57
Maximum Fall	1939 -1.68	1932 -0.82	1901 -0.63	1925 -0.05	1948 -0.10	1919 -0.21	1919–21 -0.32	1913 -0.49	1948 -0.56	1924 -0.65	1919 -0.48	1955–56 -1.86
Average	-0.326	+0.473	+0.624	+0.309	+0.188	+0.073	-0.115	-0.225	-0.277	-0.299	+0.002	-0.421

Average 1898–1968: 573.013

TABLE 11-16 Lake Erie Water Level Data at Cleveland, Ohio

Stages (Feet above sea level)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	1886 571.62	1952 572.06	1952 572.28	1952 572.67	1952 572.76	1952 572.73	1862[a] 572.51	1861[a] 572.22	1861 572.04	1861 571.81	1861 571.79	1885 571.60
Low	1935 567.62	1936 567.49	1934 567.65	1934 568.20	1934 568.43	1934 568.46	1934 568.46	1934 568.36	1934 568.23	1934 567.95	1934 567.60	1934 567.53
Mean	569.843	569.793	570.007	570.546	570.881	571.035	570.994	570.807	570.530	570.196	569.931	569.859
Changes (in feet)	**Jan-Feb**	**Feb-Mar**	**Mar-Apr**	**Apr-May**	**May-Jun**	**Jun-Jul**	**Jul-Aug**	**Aug-Sep**	**Sep-Oct**	**Oct-Nov**	**Nov-Dec**	**Dec-Jan**
Maximum Rise	1952 +0.67	1887 +0.78	1913 +1.57	1947 +0.95	1892 +0.76	1902 +0.63	1915 +0.26	1926 +0.13	1926 +0.28	1917 +0.14	1927 +0.52	1949-50 +0.78
Maximum Fall	1886 -0.73	1931 -0.31	1891 -0.13	1891 -0.18	1930 -0.21	1890 -0.38	1868 -0.52	1937 -0.57	1871 -0.67	1924 -0.64	1882 -0.51	1917-18 -0.67
Average	-0.050	+0.214	+0.540	+0.335	+0.154	-0.041	-0.187	-0.277	-0.329	-0.265	-0.072	-0.025

Average 1860-1968: 570.369
Average 1900-1968: 570.133

[a]Also occurred in 1952

TABLE 11-17 Lake Ontario Water Level Data at Oswego, New York

Stages (feet above sea level)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High	1886 246.40	1886 246.47	1952 246.77	1952 247.60	1952 247.95	1952 248.06	1947 247.74	1947 247.45	1947 246.91	1861 246.49	1861 246.56	1861 246.35
Low	1935 241.67	1936 241.59	1935 242.08	1935 242.38	1935 242.67	1935 242.91	1934 242.75	1934 242.26	1934 241.94	1934 241.72	1934 241.45	1934 241.48
Mean	244.122	244.188	244.454	245.072	245.454	245.612	245.539	245.217	244.804	244.438	244.203	244.124
Changes (in feet)	**Jan-Feb**	**Feb-Mar**	**Mar-Apr**	**Apr-May**	**May-Jun**	**Jun-Jul**	**Jul-Aug**	**Aug-Sep**	**Sep-Oct**	**Oct-Nov**	**Nov-Dec**	**Dec-Jan**
Maximum Rise	1887 +0.76	1903 +0.82	1873 +1.90	1893 +1.14	1947 +1.12	1883 +0.54	1915 +0.30	1915 +0.03	1945 +0.36	1926 +0.31	1927 +0.80	1906-07 +0.63
Maximum Fall	1963-64 -0.51	1885[a] -0.29	1915 -0.23	1891 -0.23	1891 -0.41	1955 -0.51	1960 -0.69	1908 -0.80	1862 -0.95	1867 -0.75	1867 -0.77	1917-18 -0.58
Average	+0.066	+0.267	+0.617	+0.382	+0.158	-0.073	-0.322	-0.414	-0.366	-0.235	-0.078	-0.012

Average 1860-1968: 244.770
Average 1900-1968: 244.620

[a]Also occurred in 1967

shoreward. Shallow lake bottoms cause the waves to break and form again. Each reformation diminishes the original height. Wind generated waves are of interest because the wave run-up on the beach, or at a structure, contributes to the maximum water level along the shoreline. (See Section 8 for a discussion of wave run-up.)

At any place on a Lake, the probable maximum water level would result from a combination of high general average lake level, plus a large temporary rise associated with the locality. The maximum level is of interest at localities where high water levels have an adverse effect on shore property.

Lake levels represent an integration of the effects of variations in the supply factors and in the operation of the Great Lakes as a regional hydraulic system. Diversions of water into or out of the Lakes modify the supplies. Regulation of the lake ouflows and changes in the outlet channels may be considered as a modification of the system.

4.4.4 Recorded Levels

Tables 11–13 through 11–17 show the mean, maximum, and minimum monthly level values for each Lake, and the years they have occurred. These tables also list similar values for monthly changes in elevation. These data provide the range of changes in levels on a month-to-month basis and have been recorded since 1860.

A stage-duration curve utilizing recorded monthly levels is provided for each Lake in Figures 11–7 through 11–11. In using these figures note that man-made changes can affect recorded elevation. Significant changes are regulation of outflows from Lake Superior (1921) and Lake Ontario (1960); diversion of water from the Hudson Bay basin into Lake Superior (1939); diversion from the Lake Michigan basin into the Mississippi River basin at Chicago (about 1848); and changes in the natural outlet channels from the Lakes throughout the period of record.

Section 5

NATURAL FACTORS AFFECTING THE GREAT LAKES LEVELS

5.1 General

Factors that affect seasonal and yearly fluctuations of the Great Lakes levels can be separated into categories, natural and artificial. Natural variations in lake levels include changes in precipitation, runoff, evaporation, varying ice conditions that retard outflows, and transitory variations due to barometric pressure changes and wind action.

The changing levels of each of the Great Lakes depend on the balance between quantities of water received by the Lake and the quantities of water removed from it. The supplies of water to the Lakes and quantities removed from them are changing continually due to natural hydrologic variations. Water supplies to the Great Lakes system consist principally of precipitation falling on the Lake and runoff from the land areas of the Basin. For each of the lower Lakes in the system, outflow from the Lake above augments the supply to the Lake's own basin. Evaporation reduces the total supply reaching any one of the Lakes.

5.2 Precipitation

Precipitation is the primary source of water in the Great Lakes Basin. Precipitation on the water surfaces is a major factor. The average yearly precipitation over the Basin is approximately 31 inches. The normal precipitation pattern over the Great Lakes increases from 30 inches in the Lake Superior basin to 34 inches in the Lake Ontario basin. During the winter months, precipitation is normally less than in the May-September period. The Lake Survey Center calculates monthly and annual precipitation on the drainage basin of each Lake from records of the U.S. National Weather Service and the Atmospheric Service of the Department of Environment, Canada.

At present there is a network of approximately 500 precipitation stations in the Great Lakes Basin. Of these, 300 are in the U.S. and 200 in Canada. The distribution of stations over the Great Lakes Basin varies from an average of one station for every 160 square miles in parts of the Lake Erie basin to one for every 1,100 square miles in parts of the Lake Superior basin.

Stations situated around lake peripheries are used to determine the precipitation over each Lake. Precipitation records of stations on islands in the northeastern part of Lake Michigan, compared with concurrent records of precipitation stations at nearby shore stations, indicate that seasonal variations of over-lake precipitation differ from those of over-land precipitation. Over-lake precipitation in the warm months of a 10-year period was approximately nine percent less than precipitation at nearby land stations. For the cold months it was nearly nine percent greater than at the land stations. A conclusive assessment of the accuracy of measuring precipitation on the lake surface, as indicated by shore station records, is not yet possible. It is believed, however, that such variation between over-lake and over-land precipitation is a fairly reliable representation on a long-term basis.

Table 11–18 shows the average, maximum, and minimum annual precipitation on the Lake basins over the period 1900–1969. Table 11–19 shows the average monthly and annual values of precipitation for the period of record on the Lake basins. Table 11–20 shows the maximum and minimum amounts by months for each year of record.

5.2.1 Over-Water Precipitation

Precipitation on the water surface of the Great Lakes is a direct contribution to their water supply and affects lake levels immediately. However, the water area of each Lake makes direct measurements of over-water precipitation extremely difficult. The Lake Survey Center, NOAA, prepares precipitation estimates over lake surfaces using perimeter stations as the most representative measurements generally available.

Based on the computation of precipitation on the water surface of the Lakes, Table 11–21

TABLE 11-18 Annual Precipitation on Great Lakes Basins in Inches

Lake Basin	Average	Maximum	Minimum
Superior	29.56	37.96 (1968)	23.99 (1917)
Michigan	31.16	37.82 (1959)	22.21 (1930)
Huron	31.26	39.03 (1951)	25.83 (1914)
Erie	33.79	42.63 (1950)	24.48 (1963)
Ontario	34.18	43.06 (1945)	27.58 (1934)
Total Great Lakes	31.46	---	---

TABLE 11-19 Average Monthly Precipitation on Great Lakes Basins in Inches 1900–1969

	Superior	Michigan	Huron	Erie	Ontario	Entire Great Lakes
Jan	1.83	1.73	2.34	2.53	2.70	2.14
Feb	1.43	1.53	1.95	2.10	2.38	1.78
Mar	1.66	2.05	2.10	2.70	2.62	2.12
Apr	2.01	2.71	2.37	3.08	2.80	2.49
May	2.70	3.24	2.72	3.20	3.03	2.93
Jun	3.27	3.43	2.82	3.31	2.98	3.17
Jul	3.15	3.07	2.79	3.20	3.14	3.05
Aug	3.16	3.07	2.82	3.03	2.97	3.01
Sep	3.45	3.41	2.79	2.92	2.96	3.24
Oct	2.58	2.65	2.75	2.66	2.94	2.72
Nov	2.42	2.43	3.20	2.60	2.92	2.61
Dec	1.90	1.84	2.83	2.46	2.74	2.20
Annual	29.56	31.16	31.26	33.79	34.18	31.46

TABLE 11-20 Maximum and Minimum Monthly Precipitation on the Great Lakes Basins in Inches and Year of Occurrence 1900–1969

Lake Basin		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Superior	Max.	3.62	3.20	3.25	4.09	4.31	6.21	5.60	5.54	6.61	4.28	4.40	4.29
	Year	1935	1939	1951	1938	1927	1943	1952	1959	1941	1946	1926	1968
	Min.	0.76	0.48	0.38	0.71	0.86	0.89	1.25	1.02	1.37	0.59	0.46	0.35
	Year	1961	1912	1910	1949	1948	1910	1936	1930	1948	1947	1939	1913
Michigan	Max.	3.33	3.31	3.40	5.32	5.45	6.59	6.00	6.14	7.08	5.98	5.13	3.41
	Year	1950	1938	1948	1929	1912	1969	1952	1940	1952	1954	1937	1968
	Min.	0.63	0.32	0.44	0.89	1.23	1.09	0.98	0.82	1.41	0.46	0.33	0.51
	Year	1956	1969	1910	1901	1925	1910	1936	1969	1965	1924	1904	1913
Huron	Max.	3.74	3.77	4.01	4.61	5.10	5.12	4.46	4.52	5.41	6.04	5.45	4.05
	Year	1929	1908	1921	1929	1945	1967	1952	1959	1965	1954	1966	1920
	Min.	1.06	0.81	0.61	1.13	0.91	1.22	1.00	0.90	1.10	0.63	0.94	0.61
	Year	1956	1934	1915	1935	1920	1909	1916	1927	1948	1939	1939	1913
Erie	Max.	5.87	4.21	6.71	5.79	6.78	6.37	6.22	5.87	6.93	7.64	6.11	4.42
	Year	1950	1908	1913	1929	1943	1902	1915	1956	1926	1954	1927	1900
	Min.	0.61	0.58	0.43	0.93	0.97	1.58	1.15	1.35	0.77	0.44	0.39	0.87
	Year	1961	1969	1910	1946	1934	1952	1930	1930	1908	1924	1904	1923
Ontario	Max.	4.61	4.17	5.33	4.99	5.64	5.55	6.15	5.27	6.13	7.99	6.61	4.82
	Year	1937	1960	1936	1929	1943	1922	1902	1915	1945	1955	1927	1942
	Min.	1.14	0.95	0.72	1.12	0.63	1.20	1.28	1.27	0.99	0.46	0.61	1.07
	Year	1921	1969	1915	1915	1920	1912	1936	1907	1964	1963	1904	1943
Entire Great Lakes	Max.	3.98	3.15	3.81	4.18	4.62	4.76	4.72	4.70	5.32	5.15	4.22	3.75
	Year	1950	1908	1913	1929	1943	1943	1952	1959	1965	1954	1927	1968
	Min.	0.90	0.62	0.60	1.12	1.32	1.43	1.28	1.13	1.60	0.77	0.71	0.66
	Year	1961	1969	1910	1915	1934	1910	1936	1930	1948	1924	1904	1913

TABLE 11–21 Average Monthly Precipitation on Water Surface of Lakes in Inches 1935–1964

	Superior	Michigan	Huron	Erie	Ontario
Jan	2.21	1.83	2.62	2.48	2.64
Feb	1.65	1.57	2.07	2.38	2.60
Mar	1.80	1.98	2.13	2.76	2.71
Apr	2.35	2.72	2.48	3.29	2.81
May	3.02	3.02	2.75	3.12	2.96
Jun	3.47	3.23	2.76	3.20	2.47
Jul	2.82	2.90	2.64	2.94	2.89
Aug	3.37	3.11	2.84	3.14	2.83
Sep	3.35	3.30	3.28	2.80	2.75
Oct	2.36	2.32	2.65	2.63	2.68
Nov	2.73	2.42	2.90	2.69	2.74
Dec	2.17	1.78	2.81	2.32	2.71
Annual	31.30	30.18	31.93	33.81	32.79

shows the monthly values for the 1935–1964 period. Experts chose this period to coincide with the estimated runoff values provided in Tables 11–22 and 11–23.

5.3 Runoff

The land areas tributary to the Great Lakes are peripheral bands around the lakeshores which vary outward from the lakeshores from less than 10 miles to approximately 100 miles. The stream systems, collecting land drainage and discharging it into the Lakes, have many constant and some intermittent flowing streams.

Although the annual amount of precipitation has a large bearing on the total runoff in the Great Lakes Basin, seasonal distribution of precipitation and the north-south temperature gradient are equally important. For example, even though the Lake Erie basin re-

TABLE 11–22 Average Monthly Runoff into the Lakes in Cubic Feet per Second per Square Mile

Month	Ontario	Erie	St. Clair	Huron	Michigan	Superior
January	1.14	1.23	0.88	0.62	0.75	0.43
February	1.15	1.37	1.12	0.67	0.72	0.36
March	2.58	2.19	1.93	1.43	1.16	0.54
April	3.07	1.89	1.56	2.65	1.72	1.95
May	1.48	0.97	0.84	1.70	1.17	2.74
June	0.69	0.58	0.46	0.94	0.80	1.66
July	0.45	0.29	0.27	0.65	0.57	0.99
August	0.35	0.20	0.21	0.44	0.49	0.60
September	0.36	0.16	0.18	0.46	0.54	0.67
October	0.54	0.26	0.30	0.61	0.60	0.77
November	0.84	0.46	0.43	0.86	0.69	0.85
December	1.03	0.75	0.75	0.83	0.60	0.64
Average	1.14	0.86	0.74	0.99	0.82	1.02
Square Miles Tributary Land Area	24,700[1]	23,600[2]	6,090[3]	51,800[4]	45,600	49,300
Average cfs	28,100	20,000	4,500	51,300	37,400	50,300
Equivalent Inches on Lake	4.27	2.28	11.70	2.49	1.87	1.77

[1]Including Niagara River
[2]Including Detroit River
[3]Including St. Clair River
[4]Including St. Marys River

TABLE 11-23 Average Monthly Runoff in Inches on Lakes 1935-1964

Month	Ontario	Erie	Huron	Michigan	Superior
January	4.42	4.06	1.61	1.77	0.77
February	4.06	4.20	1.58	1.54	0.59
March	10.01	7.49	3.71	2.73	0.97
April	11.53	6.17	6.63	3.92	3.38
May	5.74	3.29	4.41	2.76	4.91
June	2.59	1.90	2.36	1.83	2.88
July	1.75	1.02	1.69	1.34	1.78
August	1.36	0.70	1.14	1.16	1.08
September	1.35	0.54	1.16	1.23	1.16
October	2.10	0.95	1.58	1.41	1.38
November	3.15	1.52	2.16	1.57	1.47
December	4.00	2.63	2.16	1.41	1.15
Annual	52.06	34.47	30.19	22.67	21.52

Based on Table 1, Runoff Characteristics in the Great Lakes Basin, R.L. Pentland, 1968

ceives 15 percent more precipitation than the Lake Superior basin, annual runoff into Lake Erie is 15 percent less. This is partly because the Lake Erie basin receives less than 60 percent as much snowfall, and loses most of its snowpack through winter thaws. Snow accumulation is a highly efficient source of runoff.

High evapotranspiration losses during the growing season (May-August) help cause a rapid recession in runoff during the summer months throughout the Basin. A sharp drop in evapotranspiration in October and November contributes to increasing runoff during these months, even though precipitation amounts are normally decreasing.

The average spring runoff comes first on the Lake Erie basin because of its southern location. The spring runoff from the basins of Lakes Ontario, Michigan, and Huron normally occurs a month later than that from the Lake Erie basin, and Lake Superior basin runoff occurs two months later.

5.3.1 Runoff Variations

Climatic and physical characteristics of the tributary basins determine the variations in runoff distribution. Appendix 2, *Surface Water Hydrology*, provides complete runoff analysis of major tributaries to each Lake and their characteristics. Characteristic values of annual average runoff vary for the various streams in the Great Lakes Basin from approximately 0.5 cfs to 2.0 cfs per square mile of land. Table 11-22 shows estimated monthly and annual runoff into the Lakes for the period 1935-1964.[33] Table 11-23 provides the same values in inches for each Lake.

5.3.2 Lake Superior Basin Runoff

The main tributary to Lake Superior is the Nipigon River in Ontario, with a total drainage area of 20 percent of the total land area tributary to that Lake. The Ogoki Project diversion into Lake Nipigon augments the flow of the Nipigon River. Section 6 describes this project. The drainage areas of other tributaries to Lake Superior are much smaller. The largest of these is the Kamistikia River in Ontario, draining approximately seven percent of the basin.

5.3.3 Lakes Michigan-Huron Basin Runoff

The largest tributaries to Lake Michigan are the Fox River in Wisconsin and the Grand River in Michigan, which drain 26 percent of the Lake's drainage area. Largest tributaries to Lake Huron are the Saginaw River in Michigan and the French River in Ontario. These account for 24 percent of the area tributary to Lake Huron.

5.3.4 Lake Erie Basin Runoff

Streams discharging into the St. Clair-Detroit River system are considered tributaries to Lake Erie. The Thames River in Ontario is the largest tributary draining into Lake St. Clair. The Maumee River in Ohio and Indiana, and the Grand River in Ontario are the largest tributaries to Lake Erie. These three rivers account for 39 percent of the tributary area of the Lake Erie basin.

5.3.5 Lake Ontario Basin Runoff

The Oswego River in New York and the Trent River in Ontario are the largest tributaries to Lake Ontario. They account for 41 per cent of the total tributary area to Lake Ontario.

5.3.6 Stream-Gaging Stations

Stream-gaging stations in the Great Lakes Basin are operated by the U.S. Geological Survey, Department of the Interior, and by the Water Survey of Canada, Department of Environment. The approximate percentages of tributary land areas in the United States and Canada covered by stream-gaging records are shown in Table 11-24.

TABLE 11-24 Percentage of Tributary Area with Gaged Stream Flows

Lake Basin	Total Basin	United States	Canada
Superior	53	53	53
Michigan	69	69	--
Huron	59	63	57
Erie	66	75	45
Ontario	60	69	48

5.4 Ground Water

No extensive investigations have been made to show the direct contribution of ground water to the Great Lakes. Some water is known to be directly contributed to the Lakes by subterranean movement. This is in addition to ground water which seeps into stream channels and is included in the runoff.

The U.S. Geological Survey has estimated that the direct ground-water contribution to the entire Great Lakes is nearly 2,000 cubic feet per second. This is relatively small compared with the amount the Lakes receive from precipitation on the water surface and from runoff from the land drainage area.

A lake may derive some of its water from ground-water seepage, or lose water to the ground-water system through lakebed seepage. Studies are needed on the Great Lakes to locate areas of significant ground-water recharge. Further discussions on this subject are included in Appendix 3, *Geology and Ground Water.*

5.5 Evaporation

Evaporation is the net water loss from the continuous process of vaporization. There is no direct method of measuring evaporation from bodies as large as the Great Lakes. Actual evaporation losses depend directly upon climatologic and meteorologic factors.

Due to the important effect of evaporation on the availability of water in the Lakes, on water quality, and on the heat budget of the Lakes, its determination is essential. Researchers have tried several independent methods to determine evaporation from the water surfaces: water budget, mass transfer, energy budget, and evaporation pan observations. The water budget and mass transfer methods have been used most often.

Evaporation is basically a cooling process. Colder regions provide smaller evaporation opportunities, so evaporation from the Lake Superior basin, in the cooler part of the Great Lakes, is small compared to evaporation from the Lake Erie basin. Another important factor affecting evaporation directly from the water surface of the Great Lakes is the Lakes' heat storage capacity, which depends on their depths. Deeper lakes warm up and cool down more slowly, producing a delayed shift in the seasonal low and high evaporation losses.

Recent investigations have determined average annual amounts of evaporation for the individual Lakes as follows: Lake Superior, 21 inches; Lakes Michigan-Huron, 26 inches; Lake Erie, 33 inches; and Lake Ontario, 28 inches. Seasonal variations in the average monthly evaporation directly from the Great Lakes, based on various studies,[11] are shown in smooth graphs (Figure 11-12).

The lowest average evaporation generally occurs in the spring when the water temperature is close to or below the dew-point temperature of the air. This evaporation varies from slight evaporation to some condensation. With gradually increasing air temperatures, the water temperature increases rapidly, and evaporation increases accordingly. The largest amount of evaporation occurs in the fall when the water temperature is considerably higher than the dew-point temperature of the air.

5.6 Crustal Movement

Another factor which affects the levels of the Great Lakes is what geologists term crustal movement. For thousands of years there has been a more or less continuous differential uplifting of the earth's crust in the Great Lakes Basin.

The weight of glacier ice piled on the earth's crust depressed it into the weak layers below. The process of crustal rebound accompanied the surface unloading from glacial thinning and retreat. Geologists have determined that an uplift of several hundred feet has occurred in some places on the Great Lakes shores since the glacial ages.[15] Shoreline features which were level when first formed by glacial lakes are now warped upward in a northeast direction.

From the lake level records available, it appears that the land along the northern and eastern shores of the Lakes is rising with respect to the southern and western shores, and

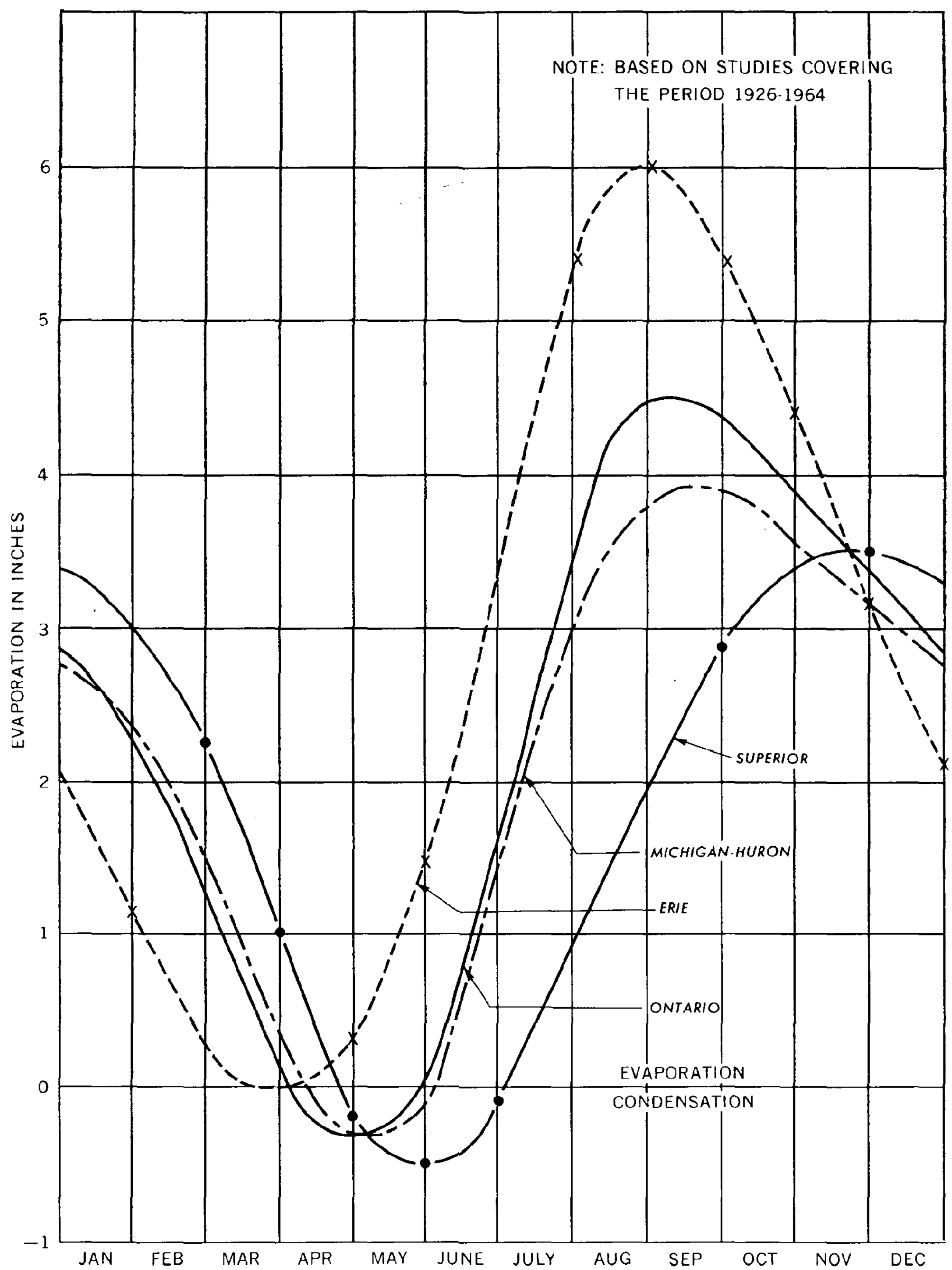


FIGURE 11–12 Evaporation from the Great Lakes

TABLE 11–25 Differential Crustal Movement Rates in Feet per 100 Years

Lake	SW Gage	NE Gage	Distance (Miles)	Rate	Rate/ 100 Miles
Superior	Marquette	Michipicoten	150	1.35	0.9
Michigan-Huron	Milwaukee	Thessalon	310	1.22	0.4
Erie	Cleveland	Port Colborne	160	0.37	0.2
Ontario	Port Dalhousie	Kingston	160	0.66	0.4

that the crustal movement is such that the land along most of the shores of each of the Lakes is subsiding relative to the land at the lake outlets. A comprehensive study of differential crustal movement in the Great Lakes area was made by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. The Committee's findings are set forth in eight interim reports, dated between May 1957 and April 1959.[8]

Table 11–25 is based on the Committee's findings, and lists the differential crustal movement between points on the shores of each Lake. Researchers and observers determined these rates from the records of pairs of water-level gages, one on the southern shore and the other on the northeastern shore in an approximately northeast direction.

These data suggest that the direction of maximum relative movement may vary appreciably over the area. The differential movement per 100 years per 100 miles indicates that the rate of such movement increases from the southern portions of the area to the northern portions.

One may readily see the effect on water levels of differential crustal movement if one visualizes the Lakes as basins which are being tilted by a gradual raising of their northeastern rims. Water levels along southwestern shores are rising faster than water levels measured at the outlet. Conversely, water levels along the shores at localities north and east of the outlet are receding with respect to the water level at the outlet.

5.7 Ice Retardation

During the winter ice affects the flows through the natural outlet channels of the Lakes. Compared with outflows from open-water relationships between lake stage and lake outflow through these channels, the recorded outflows indicate average reductions in outflow for the three-month period January through March, approximately as shown in Table 11–26.

TABLE 11–26 Estimated Retardation by Ice

Outlet River	Average Outflow in cfs	Average Retardation in cfs	Percentage of Change in Present Outflow
St. Marys	74,500	3,000	4
St. Clair	187,000	19,000	10
Detroit	190,000	4,000	2
Niagara	202,000	4,000	2
St. Lawrence	239,000	7,000	3

Ice retardation of flows causes the levels of unregulated Lakes to be higher at the time of spring breakup than under ice-free conditions. This higher stage results in a larger outflow following the breakup than would otherwise occur. The additional flow gradually lessens as the ice-induced rise in the lake level is reduced by larger outflow. Timing or severity of ice conditions on the outlet rivers is not predictable for any specific winter.

5.7.1 Lake Superior

The regulation of Lake Superior imposes an outflow limitation of 85,000 cfs because of ice conditions in the St. Marys River from early December through April. The limit was imposed largely as a result of adverse effects of ice on river levels at Sault Ste. Marie, Michigan, below the rapids. Records show that problems occurred during the early winter of 1916–1917 with a flow of 108,000 cfs. Later the same winter, a flow of 86,000 cfs was maintained without trouble. This maximum limitation has been retained by the International Joint Commission as an operational procedure for the regulation of Lake Superior.

Since 1968 an investigation has been under way to determine whether the St. Marys River has a safe winter capacity greater than 85,000 cfs, and whether it is technically feasible to operate the gates at the control structures under ice conditions. Experiments are being carried out at Sault Ste. Marie each winter to obtain answers to these questions. The results of these experiments are contained in the International Great Lakes Levels Board report which was submitted to the International Joint Commission in December 1973.

5.7.2 Lakes Michigan-Huron

For Lakes Michigan-Huron an appreciable portion of the ice-induced rise normally remains until the start of the next ice season. It has been estimated that the level of Lakes Michigan-Huron is 0.4 foot higher than it would be without ice retardation.[43]

With regard to the winter outflows from Lakes Michigan-Huron through the St. Clair River, ice retardation of the flows in the Detroit River normally is much less than in the St. Clair River. Because the inflow to Lake St. Clair is reduced more than its outflow, there is a sharp drop in the Lake St. Clair level almost every winter. A sharp rise follows, once the ice retardation is reduced or eliminated. The Lake St. Clair level may drop as much as one and one-half feet during a severe ice period, and the St. Clair River level above the ice jam may rise as much as three feet.

5.7.3 Lake Erie

Ice conditions on the Niagara River have materially restricted the Lake Erie outflow for short periods. The Lake Erie ice field near the entrance to the Niagara River usually arches between the Canadian and United States shores and restricts movement of lake ice into the river. When the ice is forming, or when the Lake is under adverse conditions of wind and temperature, the arch and the ice field behind it may break, allowing ice to enter the Niagara River in quantities greater than the river can accommodate. Such ice contributes considerably to level and flow problems on the river.

Each winter since 1964 the power entities PASNY and Ontario Hydro have installed an ice boom at the outlet of Lake Erie on a test basis. The ice boom has reduced shore property damage and losses to power production. Ice booms in the Niagara and St. Lawrence Rivers reduce flow retardation but do not eliminate it.

Regardless of the effectiveness of ice booms, the anchor ice effect continues to be present on the rivers. Section 6 provides pertinent data on the effects of ice booms.

5.7.4 Lake Ontario

The regulation plan for Lake Ontario limits maximum flow during January to permit the formation of an ice cover in critical reaches of the St. Lawrence River during February and March. Stable winter operating conditions must be maintained. The International St. Lawrence River Board of Control, under its discretionary authority, may also limit discharge that assists in forming an ice cover.

5.8 Other Natural Factors

Weeds or other aquatic growth create a certain retardation of the outflows of the outlet rivers. The Niagara River is known to be affected by weed growths from June to September. Stage-discharge equations for Lake Erie and the Niagara River are based upon open-water conditions with no aquatic growth. With these, engineers are studying the magnitude of such flow retardation. Present estimates of retardation of Niagara River flows caused by aquatic growth range up to 20,000 cfs, which is approximately 10 percent of the average flow of the river.

5.8.1 Transitory Variations

Other factors may create quite large fluctuations of lake levels, but only over short periods lasting from minutes to several days. A seiche or surge, for example, is an oscillation of the lake water surface. Wind and barometric pressure are the two most common causes. Wind-produced seiches follow cessation or shift in direction after a time of relatively steady wind from one direction. Atmospheric pressure changes may also alter lake levels. One such variation on Lake Superior occurred on June 30, 1968, reportedly producing a level variation of five to six feet above normal at one locality.

Hunt[17] and Verber[49] as well as others have described the seiche and oscillations in Lake Erie. The entire shoreline of Lake Erie undergoes these brief fluctuations at various times.

The impulses that begin in the various seiches appear to be due to wind variations.

Investigations of surges on Lake Michigan show the cause to be intense squall lines that move rapidly across the southern portion of the Lake in a direction generally toward the southeast.[23] The most prominent occurrence of a seiche in Lake Michigan produced a sudden and unexpected rise in lake level in Montrose Harbor in Chicago on June 26, 1954, causing several drownings. For some places such as for the Chicago area, the National Weather Service has developed techniques to provide seiche warnings. These warnings help to protect lives and property along the southern shores of Lake Michigan. Further studies are needed to gather more specific data on water-level variations at other localities throughout the Great Lakes.

5.8.2 Tides

True tides, both solar and lunar, occur on the Great Lakes and were observed and studied for many years. The investigations of the U.S. Coast and Geodetic Survey indicate that the spring, or combined lunar and solar tide is less than two inches. Consequently, the Great Lakes are considered to be essentially non-tidal because the fluctuations due to the gravitational pull of the moon and sun are relatively small for any diurnal period.

The lake level average gage records of many months indicate lunar tides. These smaller level changes are coincident with lunar movement. However, these minor level variations are masked by the greater fluctuations of levels produced by wind and barometric pressure conditions.

Section 6

HYDRAULICS OF THE GREAT LAKES—ARTIFICIAL FACTORS AFFECTING LAKE LEVELS

6.1 General

Various artificial factors that modify supplies, outflows, and lake levels have existed for many years. Their net effects are sometimes superimposed on the levels and outflows. Artificial factors are diversions of water to and from the Lakes and changes in outflows from natural outlets by channel changes and regulatory works.

The significant artificial factors affecting the lake levels are listed in order from the farthest upstream to the farthest downstream:

(1) Long Lake and Ogoki diversions into the Lake Superior basin

(2) regulatory works on the St. Marys River

(3) diversions out of the Lake Michigan basin at Chicago

(4) channel changes in the St. Clair-Detroit River systems

(5) diversion out of Lake Erie via the Welland Canal

(6) channel changes in the St. Lawrence River

(7) regulatory works on the St. Lawrence River

The regulation of Lake Superior outflow slightly modifies the levels of the other Lakes. The regulation of Lake Ontario outflow does not affect the levels of the other Lakes, but does affect levels downstream on the St. Lawrence River. Artificial control effects are predictable, and are quite small when compared to natural variations in lake levels. The present estimated net effects of artificial control on the lake levels are summarized in Table 11–27.

Diversion implies a transfer or bypassing of a fixed amount of water from one point of a lake or connecting river to another point downstream, or from one lake to another lake downstream through works constructed by man. Figure 11–13 shows the comparative value of diversions into and out of the Great Lakes system and natural inflows and outflows of the Lakes. These man-made factors are important because they ultimately cause an increase or decrease in the natural lake levels.

6.1.1 Effects of Diversion on Lake Levels and Outflows

A continuous diversion of water into or out of the Great Lakes Basin increases or decreases the supply to the Lakes downstream from the diversion.

The change in supply ultimately changes the outflows from the downstream Lakes equal to the amount of the diversion. Changes in outflow in turn affect the levels of the Lakes. Existing diversions minutely influence the levels of Lakes Superior and Ontario because the rule curves by which the Lakes are regulated have allowed for these diversions. The Long Lake and Ogoki diversions increase the levels of Lakes Michigan-Huron and Erie by a certain amount, partially compensated for by a decrease caused by the diversion out of the Basin at Chicago.

The diversion of water out of Lake Erie through the Welland Canal ultimately de-

TABLE 11–27 Approximate Present Net Total Effects on Lake Levels of All Artificial Factors

Lake	Present Net Effect
Superior	Levels are regulated in accordance with Orders of Approval of the International Joint Commission dated May 26-27, 1914. Presently being regulated in accordance with the 1955 Modified Rule of 1949.
Michigan and Huron	Levels are lowered by 0.9 foot as a result of artificial factors, exclusive of the varying effect of the regulation of Lake Superior.
Erie	Levels are lowered 0.2 foot as a result of artificial factors, exclusive of the varying effect of the regulation of Lake Superior.
Ontario	Levels are regulated in accordance with Orders of Approval of the International Joint Commission dated October 29, 1952 and July 2, 1956. Presently being regulated in accordance with Plan 1958-D.

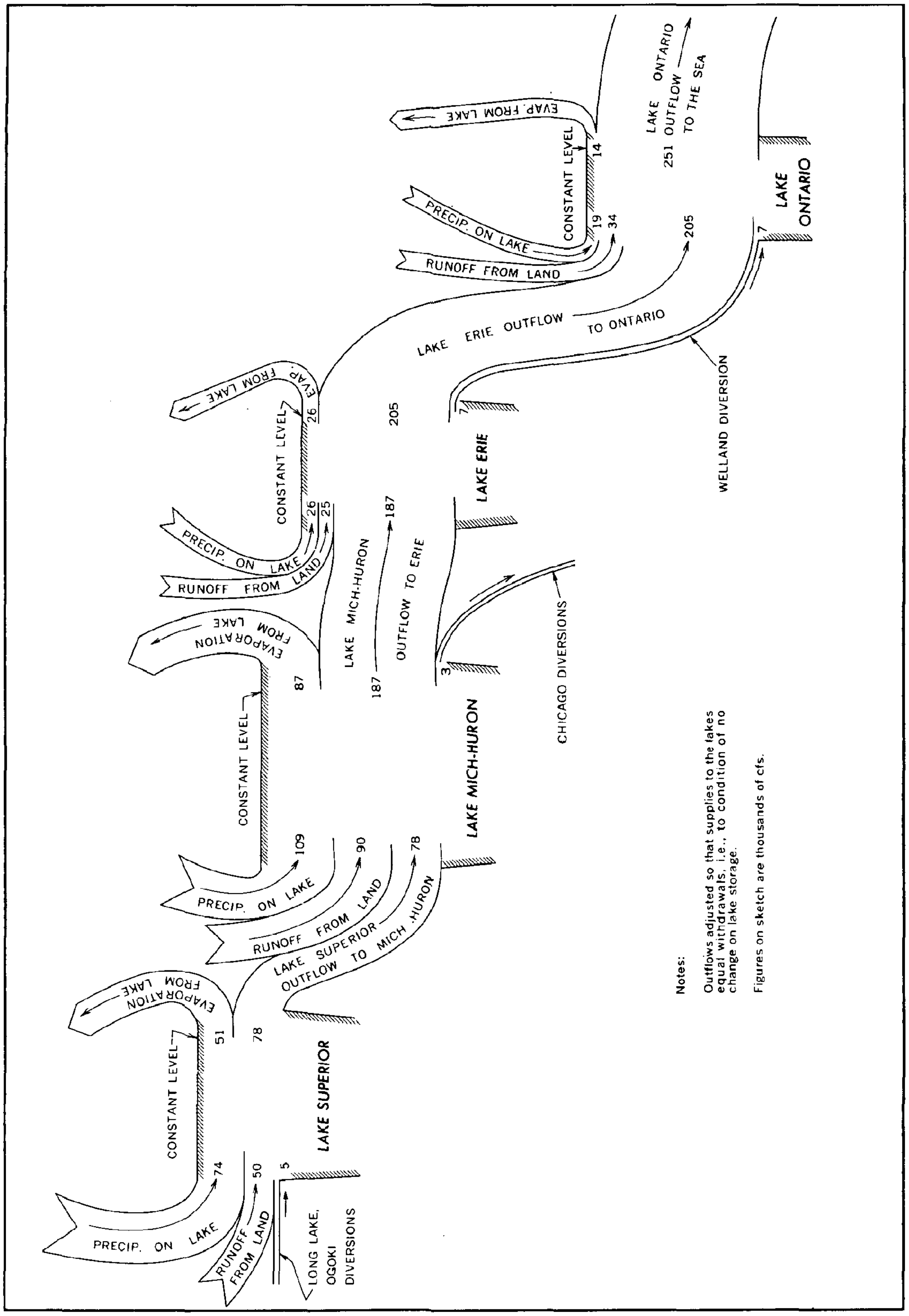


FIGURE 11-13 Factors of Water Supply to the Lakes—Average Values for October 1950-September 1960

creases the outflow of the Niagara River by the amount of the diversion. However, the increased discharge capacities of the Niagara River and Welland Canal combined have lowered the level of Lake Erie. The lower Lake Erie levels in turn lower Lakes Michigan-Huron levels because of the backwater effect in the St. Clair-Detroit River connecting channel. Both the Welland Canal and the Niagara River flow into Lake Ontario. Since there is no change in the total inflow to Lake Ontario, there is no change to Lake Ontario supplies. Figure 11–14 is a map of the Great Lakes showing locations of present diversions.

6.1.1.1 Long Lake-Ogoki Diversions

Diversions of water from the Albany River basin through the Long Lake and Ogoki Projects in Canada, beginning in 1939 and 1943 respectively, have increased Lake Superior's natural supply. Notes dated October 14 and 31, and November 7, 1940,[12] exchanged between the governments of the United States and Canada, govern waters diverted into the natural drainage of the Great Lakes through the existing Long Lake-Ogoki Works. Since 1945, the total diversion has been at an average rate of 5,000 cfs.

The Long Lake diversion channels the headwaters of the Kenogami River (which originally drained through the Kenogami and Albany Rivers into Hudson Bay) into Long Lake and the Aguasabon River, which discharges into Lake Superior near Jackfish, Ontario, 155 miles east of Thunder Bay, Ontario.

The diversion works comprise two concrete dams and a channel five and one-half miles long. The north, or control dam is on the Kenogami River, 15 miles below the former outlet of Long Lake. The south or regulating dam is five miles below the south end of Long Lake. It connects to Long Lake by a channel built across the divide and through a chain of small creeks and lakes. These two dams, 82 miles apart, control a storage area of 62.3 square miles. These works divert the runoff from 1,630 square miles of the Hudson Bay drainage basin into the Great Lakes.

The diversion was first started to flush pulp logs through the Aguasabon River. In 1948, a hydroelectric power plant was constructed on the river to utilize the increased flow. Since 1940 the supply to Long Lake has averaged approximately 1,700 cfs. Of this amount, 1,450 cfs has been diverted to Lake Superior. The remainder, some 250 cfs, has spilled down the Kenogami to Hudson Bay. Figure 11–15 shows the Long Lake diversion.

The Ogoki diversion sends the waters of a part of the Ogoki River, which drains through the Albany River into Hudson Bay, into the headwaters of the Little Jackfish River. This stream flows into Lake Nipigon and then through the Nipigon River into Lake Superior 60 miles east of Thunder Bay, Ontario. Four control dams form the Ogoki Reservoir, shown in Figure 11–16. Its regulation is closely related to the supply of Lake Nipigon since the diverted water forms part of the lake's supply.

Lake Nipigon, which has approximately 1,740 square miles of water area, has a storage capacity of 1,022,400 acre-feet within its storage range of 846 to 855 feet elevation. It has a relatively small drainage area of 9,484 square miles. This is augmented by the addition of 5,545 square miles from the Ogoki watershed.

Lake Nipigon is regulated by a rule curve designed to maintain the maximum dependable flow down the Nipigon River. The flow is utilized by three generating stations of the Hydro Electric Power Commission of Ontario. The maximum outflow is 20,000 cfs which keeps the lake at or below its maximum level of 855 feet. The restriction on outflow is required because of the presence of railway and highway crossings at Nipigon Village. Larger flows would cause excessive scouring of the extremely high river banks with a possible failure of the structures.

Normally all of the Ogoki water is diverted into Lake Nipigon. There are times, during excess inflow to Nipigon, that the diversion is partially or completely closed. The Nipigon rule curve calls for partial closure of the diversion to 4,000 cfs when Lake Nipigon elevation reaches 854.0 feet and full closure at 854.5 feet.

Since 1943, following the Nipigon rule curve, the diversion has been closed or reduced in flow approximately 20 times. The Ogoki Reservoir is then permitted to rise to the maximum level of 1073.67 feet and the excess inflow spilled down the Ogoki River into the Hudson Bay watershed.

The average inflow to the Ogoki Reservoir is 5,000 cfs. Approximately 4,000 cfs are diverted to Lake Superior and the remaining 1,000 cfs spilled down the Ogoki River to Hudson Bay. The Ogoki Reservoir diverts on a monthly basis from 2,000 cfs to 16,000 cfs. The latter flow actually occurred with the Ogoki Reservoir level slightly more than 1074.0 feet.

In addition to the 20 occasions mentioned, in 1951, 1952, and 1953 during the high water level on the Great Lakes, the U.S. Department

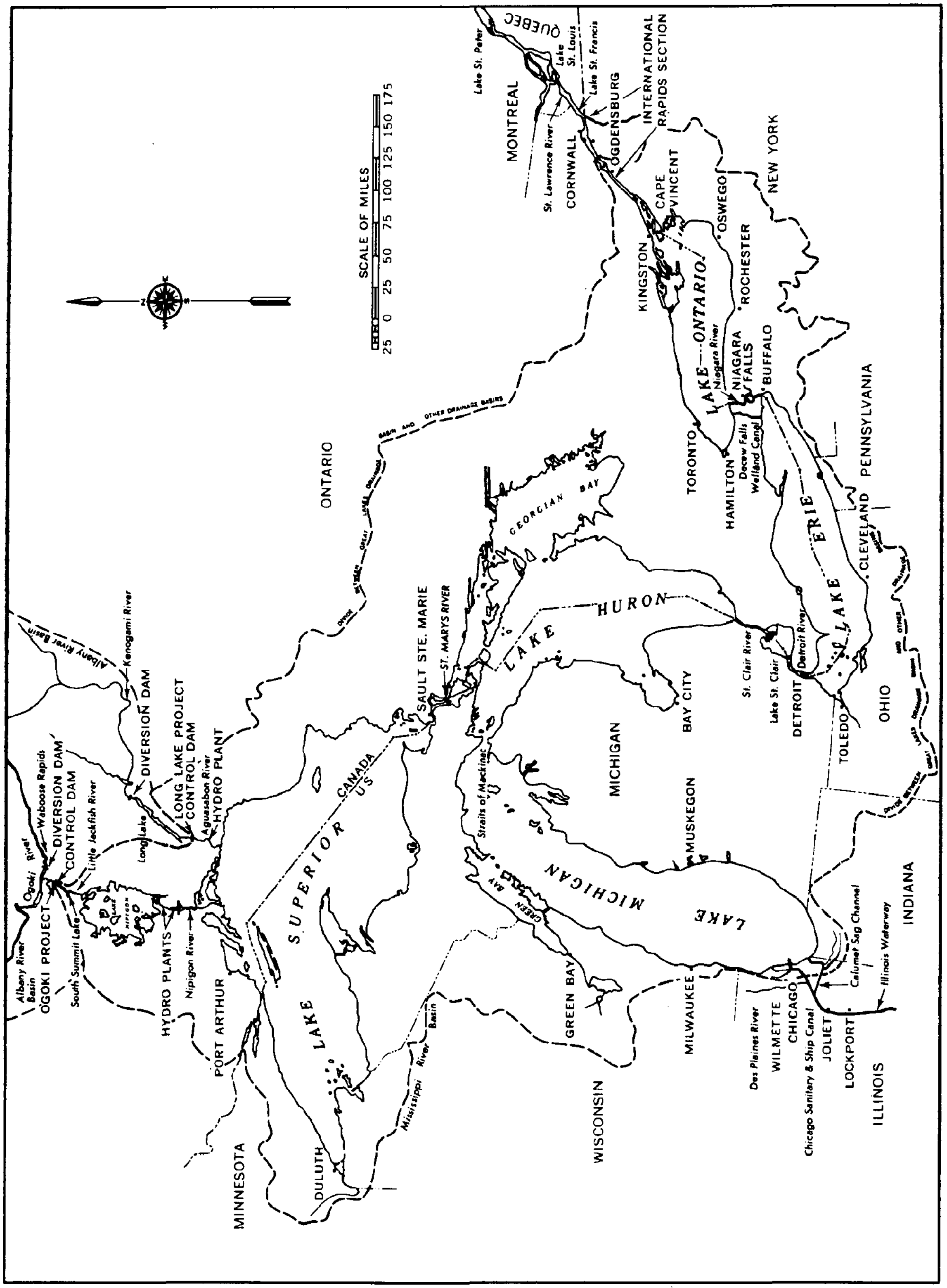


FIGURE 11-14 Sketch Map of the Great Lakes—Location of Present Diversions

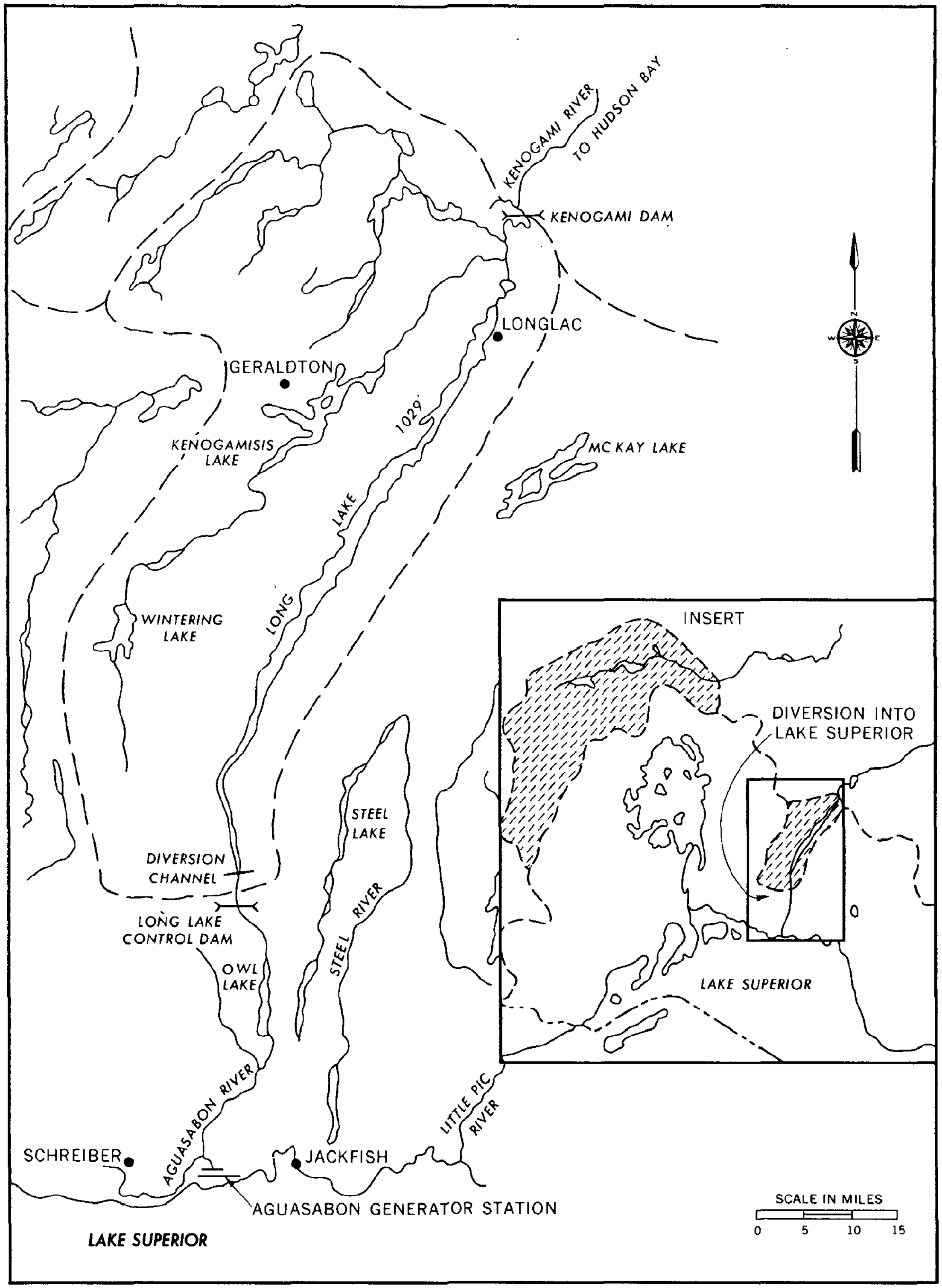


FIGURE 11–15 Long Lake Diversion

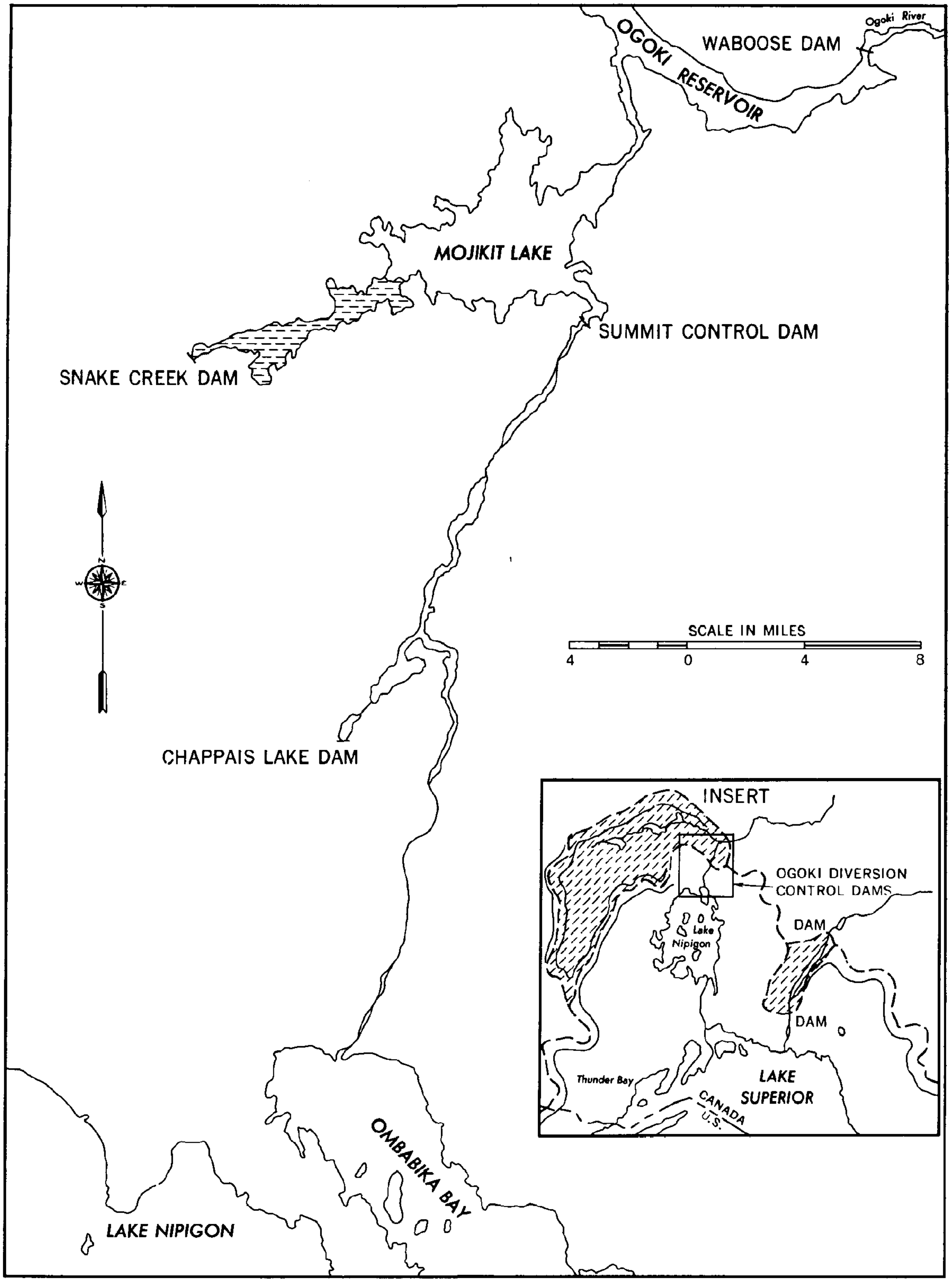


FIGURE 11-16 Ogoki Diversion Control Dams

of State requested the government of Canada to consider terminating temporarily the diversions through the Long Lake-Ogoki works. The Hydro Electric Power Commission of Ontario agreed, closing off the diversion entirely in each of the three years for part of the year and operating at reduced capacity during other parts of the year when Lake Superior and other Great Lakes levels were critical. There is, therefore, precedent for an approach by the U.S. Department of State to the government of Canada to secure a reduction in amounts being diverted through these works for the purpose of alleviating high water conditions in the Great Lakes.

The Long Lake-Ogoki diversions have raised the level of Lakes Michigan-Huron 4½ inches and of Lake Erie 2¾ inches.

6.1.1.2 Diversion out of Lake Michigan at Chicago

Water has been diverted out of the Lake Michigan basin at Chicago and into the Mississippi River drainage basin since 1848. Subsection 12.7.2 describes this diversion.

Since 1938, a United States Supreme Court decree[29] has limited the diversion to a maximum of 1,500 cfs plus pumpage, which until recently has averaged 1,600 cfs, for a total of 3,100 cfs. Recently, a Special Master of the United States Supreme Court recommended limiting the diversion to a maximum of 3,200 cfs, including domestic pumpage. The Supreme Court issued a decree to this effect on June 12, 1967.[48] This diversion has lowered the level of Lakes Michigan-Huron 2¾ inches and of Lake Erie 1⅝ inches.

6.1.1.3 Diversion through the Welland Canal

In addition to Lake Erie outflow reaching Lake Ontario through the Niagara River, some water is diverted through the Welland Canal. This water is principally used to operate the navigation locks and to generate power at the DeCew Falls hydroelectric plant, three miles west of the Canal and connected to it by a water course. Since 1950 the Welland diversion has averaged approximately 7,000 cfs. Monthly diversions are shown at the end of this appendix.

Water to feed the summit level of the original Welland Canal was diverted from the Grand River in Ontario, a tributary to Lake Erie. The diverted water was carried through the canal, some to Lake Ontario and some through the Welland River to the Niagara River. The summit level of the canal was approximately eight feet above Lake Erie level.

The Welland Canal underwent numerous changes between 1828 and 1881. In 1881 the canal summit level was lowered to the level of Lake Erie. Diverted lake water was used to supplement that drawn from the Grand River. The present diversion of water from Lake Erie is through the Welland Ship Canal. Construction of this canal started in 1913 and was completed in 1932. It connects Lake Ontario at Port Weller, Ontario, with Lake Erie at Port Colborne, Ontario, 18 miles west of the source of the Niagara River.

The Welland Canal diversion does not bring water into or take it out of the Great Lakes Basin. When engineers lowered the canal summit to the Lake Erie stage, an artificial Lake Erie basin outflow was created. The canal functions as an additional connecting channel to Lake Ontario. This diversion has lowered Lake Erie 3⅞ inches, and Lakes Michigan-Huron 1¼ inches. Figure 11–17 shows the location of this diversion.

6.1.1.4 New York State Barge Canal Diversion from the Niagara River

The New York State Barge Canal diversion is the oldest of the five diversions currently affecting Great Lakes water levels and outflows. This diversion began supplying water to the old Erie Canal in 1825. Figure 11–18 is a map of the New York State Barge Canal System. The general average canal flow is estimated at 700 cfs. During months of navigation through the canal, early April to early December, this diversion from the Niagara River is increased to 1,100 cfs. A control gate near Pendleton, New York permits the canal to be dewatered during months of nonnavigation.

6.1.1.5 Erie Barge Canal Water Levels

Water diversion is made from the Niagara River at a level comparable to the level of eastern Lake Erie. The present canal route uses part of Tonawanda Creek, then proceeds east to Lockport, New York and from there through the long-level lay to Rochester. From this point, the barge route continues east to Troy on the Hudson River. High water levels of the canal are discharged into Lake Ontario

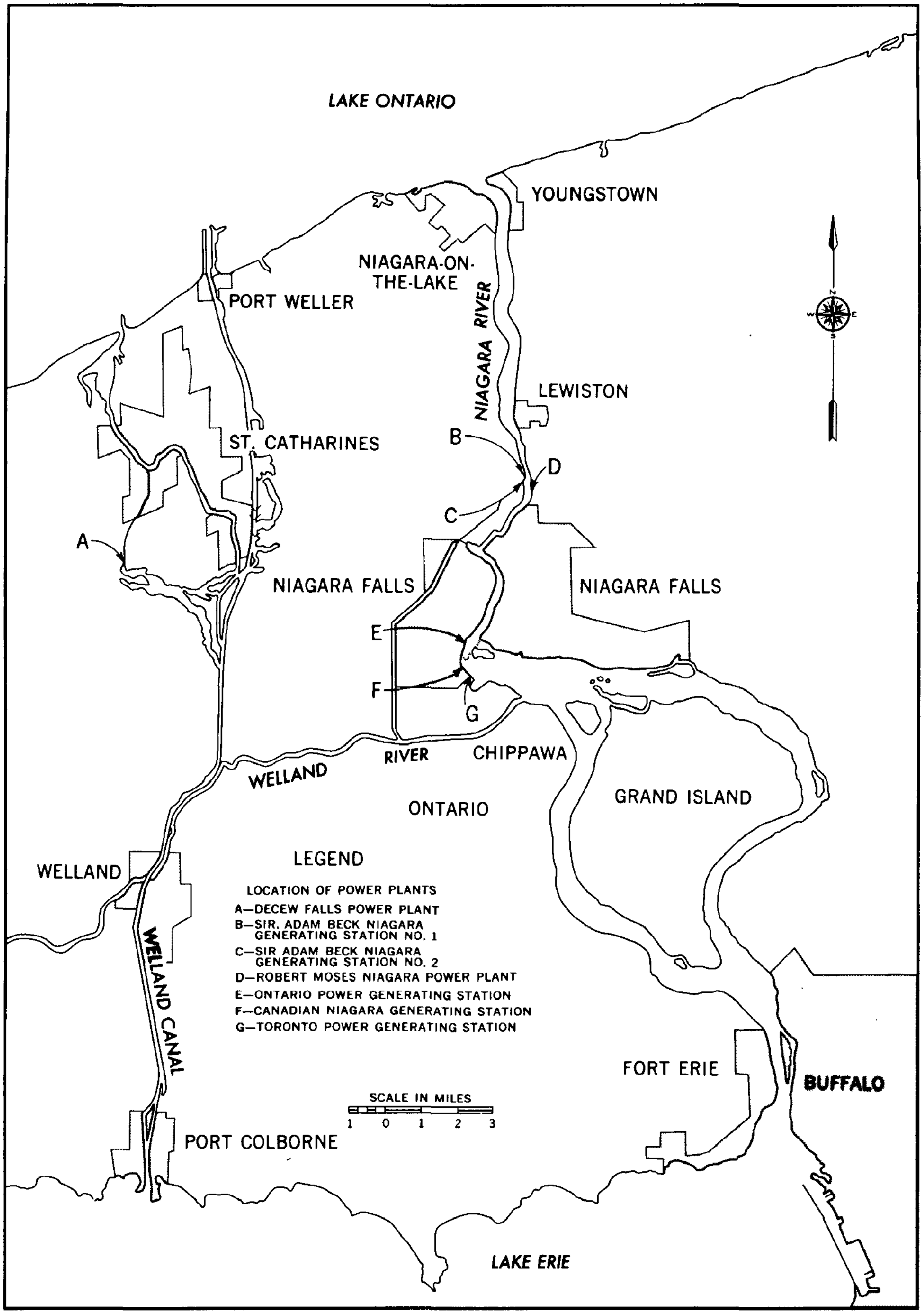


FIGURE 11–17 Welland Canal-DeCew Falls Power Plant

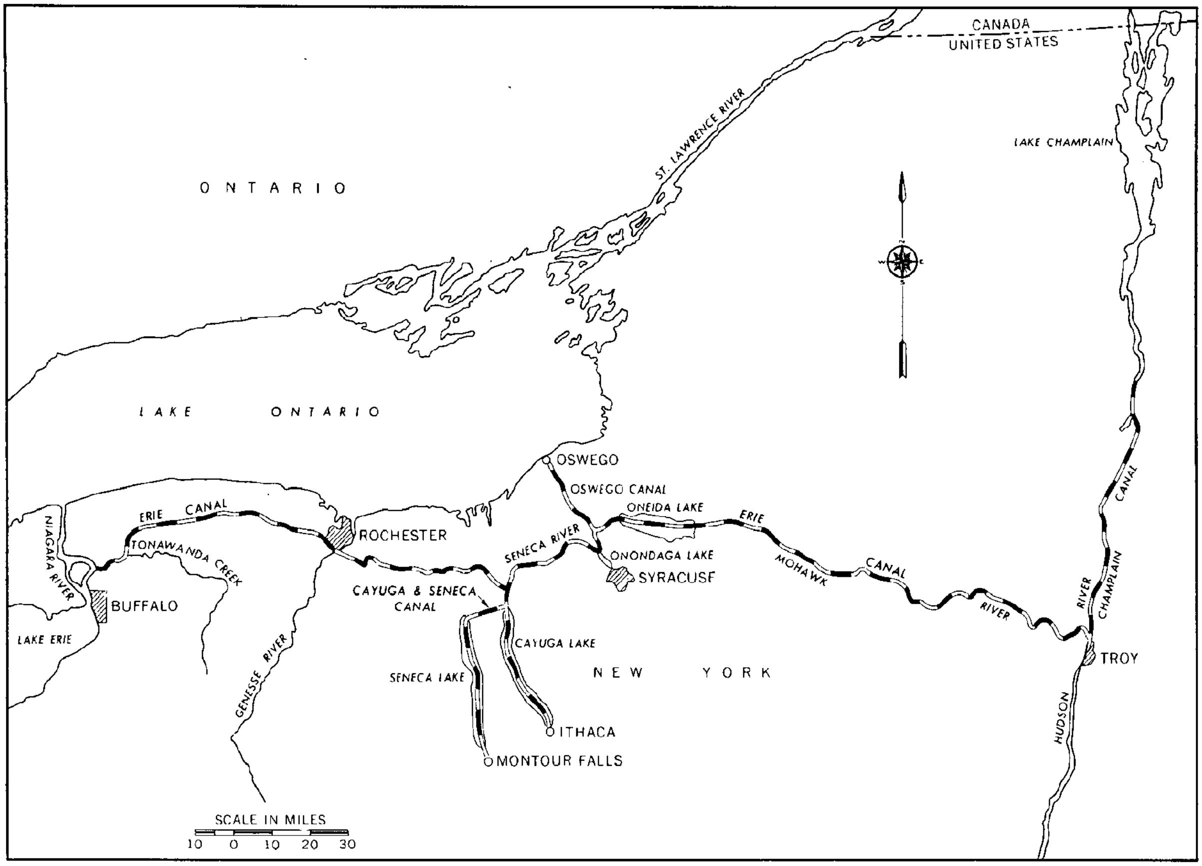


FIGURE 11–18 New York State Barge Canal System

at various places. The main overflow is through the Oswego Canal. This short route links Oswego at a junction with the main stream approximately 30 miles south of that city. New York City has had a direct water route to the Great Lakes since 1918 through the Hudson River and the Barge Canal.

6.1.1.6 Water Commerce and Hydroelectric Power

The primary use of Lake Erie water diversion is for operation of an inland waterway for shipping. Secondary uses are artifical lake level control and inland water quality control.

Some of the diversion outflow is used to energize various hydroelectric power developments at locks or other breaks in the grade of the canal. The diversions made from the Niagara River and the natural outflow of Lake Erie do not affect Lake Erie levels as much as they would if they were made directly from the Lake. Lake level studies usually overlook the effects of these small diversions.

6.1.1.7 Power Diversion at Niagara Falls

The largest diversion of water in the Great Lakes system is made from the upper Niagara River for power purposes. Diverted water is passed through the power plants and returned to the lower Niagara River. Diversions to the high-head power plants range to almost 100,000 cfs on the United States side and to approximately 66,000 cfs on the Canadian side, if sufficient water is available in the Niagara River. The Treaty of 1950 between the United States and Canada requires that 100,000 cfs flow over the Niagara Falls during daylight hours in the tourist season and 50,000 cfs at all other times.

Although these diversions are very large, control works have been constructed in the river to hold natural river levels and provide maximum water available for power purposes while providing for Treaty flow requirements to pass over the Falls. Figure 11–19 shows the relative location of the power diversions, the control structure, and Lake Erie.

The Power Authority of the State of New

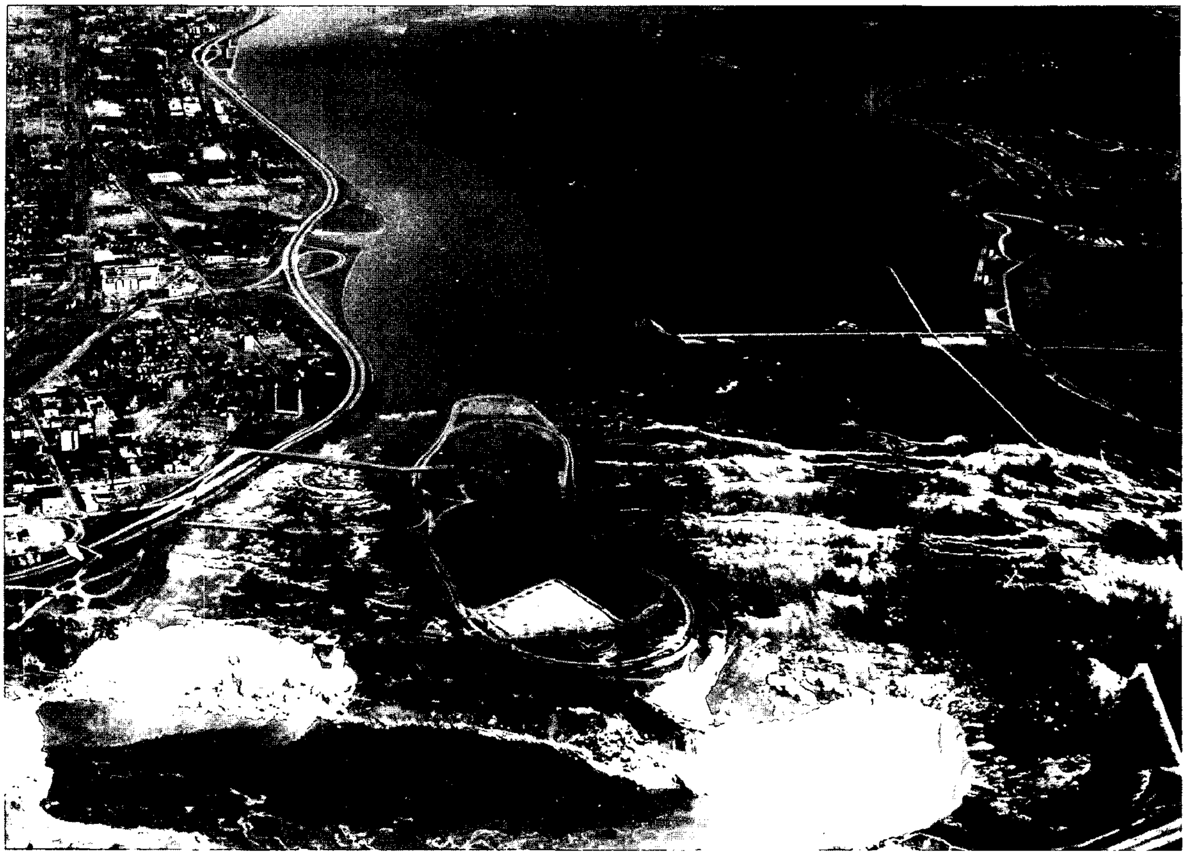


FIGURE 11-19 Niagara Falls—Power Entity Intakes and Control Structure

York diverts water through a pair of covered concrete conduits from a point approximately two miles above the Falls to a point four miles downstream from the Falls. The Hydro Electric Power Commission of Ontario diverts water through a pair of tunnels and an open canal from a point 1½ miles above the Falls to a point four miles downstream. Without compensating control works, these large diversions would have lowered levels of the Niagara River approximately four feet in the vicinity of the intakes and would have significantly lowered the levels of the rest of the upper river.

To compensate for the power diversion, a control structure has been constructed downstream from the intakes. The structure is 2120 feet long and has 18 gates each 100 feet long and 10.5 feet high. The structure is operated to maintain approximately the same levels in the upper river as would have occurred naturally for a given river flow.

River levels are maintained to a ± 0.5 foot tolerance on a daily mean basis and to a ± 0.3 foot tolerance on a monthly mean basis. Under these tolerances the effect of the Niagara River power diversions on Lake Erie levels is considered negligible.

6.2 Summary of Diversion Effects

The ultimate effects of existing diversions at the rates shown on water levels of the Great Lakes are summarized in Table 11–28. Changes in these rates will change the effects on water levels.

Diversions affect the inflows and outflows of Lake Superior and Lake Ontario, but the levels are relatively unaffected because allowances are made for such diversions in rule curves of the regulation plans. The diversion effects given in Table 11–28 are the ultimate effects of diversion, that is, the magnitude of the effects will not change if the diversion is to raise the levels of Lake Michigan by one-half inch, and to lower the levels of Lake Erie by 2¾ inches.

TABLE 11-28 Ultimate Effects of Existing Diversion on Water Levels: (+) Diversion Raises Level or (−) Diversion Lowers Level

Diversion	Long Lake-Ogoki	Chicago	Welland Canal	Net Effects
Annual Rate	5,000 cfs	3,100 cfs	7,000 cfs	
Lake Michigan-Huron	+0.37 ft. or +4 1/2 in.	-0.23 ft. or -2 3/4 in.	-0.10 ft. or -1 1/4 in.	+0.04 ft. or +1/2 in.
Lake Erie	+0.23 ft. or +2 3/4 in.	-0.14 ft. or -1 5/8 in.	-0.32 ft. or -3 7/8 in.	-0.23 ft. or -2 3/4 in.

Diversion of water may be into, out of, or within the Great Lakes Basin itself. "Out of" and "within the Basin" diversions deprive the Lake or Lakes and connecting river or rivers of the diverted quantity of water that would have increased the level or flow in that portion of the Great Lakes system.

Diversion of water into one of the Lakes from another drainage basin raises the levels and outflows of the Lake into which the water is diverted. One should not confuse a diversion with a withdrawal whereby the amount of water withdrawn from a Lake is necessarily returned to the Lake or connecting river in the same general vicinity (except for consumptive losses—that amount of water withdrawn and not returned).

Tables 11-29 and 11-30 list the diversions presently in effect in the Great Lakes Basin. These provide separate listings for United States and Canadian diversions. Additionally, future U.S. diversions known to be in the planning stage are also provided in Table 11-31.

6.3 Dredging in the St. Clair-Detroit Rivers

The 1926 report of the Joint Board of Engineers entitled "St. Lawrence Waterway" attributes approximately 0.3 foot of the lowering of Lakes Michigan-Huron levels to the commercial dredging of gravel that occurred between 1908 and 1925 from the contracted reach of the St. Clair River in the vicinity of the Point Edward Docks. In the report the remainder of the total lowering discussed (0.6 foot) is not definitely attributed to anything.

The Corps of Engineers estimates the uncompensated lowering of Lakes Michigan-Huron levels to be 0.59 foot, due to dredging for the 25-foot navigation project in the 1930s and for the 27-foot project completed in 1962. It is noted that the material dredged in deepening the channels for these projects was in large part deposited in the river in areas where it does not impede navigation.

The United States has developed preliminary plans to install submerged sills across the bed of the St. Clair River in its contracted but deep reach near Port Huron, Michigan, to provide compensation of Lakes Michigan-Huron levels for the lowering of the levels due to dredging for the 25-foot and 27-foot navigation projects. This would restore Lakes Michigan-Huron levels to 1933 conditions.

Agreement in principle exists between the two countries whereby the United States will undertake, as an integral part of these dredging projects, the installation of compensatory works to offset the effects of increased channel depths. This compensatory part of the dredging projects has not yet been carried out because the extent of the effects remains to be coordinated and agreed upon between Canada and the U.S.; the best method of compensation remains to be agreed upon; and because the matter merited a deferred decision in light of the comprehensive systems approach being developed by the International Joint Commission's present study. It would not be reasonable to provide compensation without considering the overall context of probably future major international regulation projects.

Model studies by the Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi, have determined the best location and arrangement of submerged sills as a method of compensation. Further negotiations with Canada are required to reach agreement on a specific plan. Tentative location of these sills is shown on Figure 11-20.

TABLE 11–29 U.S. Diversions of the Great Lakes

From	To	Description	Annual Average (cfs)	Period Covered
St. Marys River	St. Marys River	Edison Soo Electric Co.[1]	27,100	1959–1968
		U.S. Power Canal	12,580	1959–1968
		U.S. Navigation Canals[2]	755	1959–1968
Lake Michigan Basin	Mississippi River Basin	Chicago Metro Sanitary District and Ship Canal[3]	3,254	1959–1968
Niagara River	Lake Ontario	New York State Barge Canal	734	1959–1968
Niagara River	Niagara River	Robert Moses Niagara Powerhouse	72,100	1965–1968
		Black Rock Canal	10	1965–1968
St. Lawrence River	St. Lawrence River	St. Lawrence Powerhouse (Combined International)	252,300	1965–1968
		Long Sault Dam	For emergency uses only. No anticipated flows.	
		Massena Canal (Intake)	40	1960–1968
		Wiley-Dondero Canal[4]	590	1960–1968
Lake Huron	Lake Huron, Lake St. Clair, and Detroit River	City of Detroit Water Intake[5]	1,250 capacity	

[1] Contract Edison Soo Electric Company and Department of Army effective 30 June 1950 for 30 year period with payment of $100,000 annually for use of water.

[2] Projected 1985 estimate for combined Canadian and United States average for navigation purposes at Sault Ste. Marie is 1,000 cfs.

[3] Past Authority--The decree of the Supreme Court entered on 21 April 1930 required the reduction of the diversion then in effect and limited the diversion subsequent to 31 December 1938, to not more than an annual rate of 1,500 cfs, exclusive of domestic pumpage. Present Authority--No diverting of any of the waters of Lake Michigan or its watershed into the Illinois Waterway in excess of an average for all of them combined of 3,200 cfs. (87 Supreme Court 1774 decided 12 June 1967, effective 1 March 1970).

[4] Includes Eisenhower and Snell Locks. The 1985 estimated projection for the Snell Lock is 370 cfs plus 1180 cfs for the projected new major Cornwall Lock in 1985 (Canadian). Total estimate Cornwall and Wiley-Dondero Canal 1,550 cfs annual average.

[5] Returns of the unconsumed portion thereof to the Great Lakes system at Lake Huron (City of Flint), Lake St. Clair, and Detroit River (Zug Island).

Dikes have been constructed in the Detroit River to control the river discharge capacity by an amount equal to the enlargements in that river for the navigation channels and thus compensate for the effect of the navigation improvements on lake levels. Compensating works in the Detroit River are shown in Figure 11–21. In the St. Clair River the effect of dredging has been partially offset by depositing material excavated from the navigation channels in other areas of the river. However, the levels of Lakes Michigan-Huron have been lowered approximately seven inches by the work done in the St. Clair River for the 25-foot and 27-foot navigation projects.

6.4 Regulatory Works in the St. Marys River

Since completion of control works in the St. Marys River at Sault Ste. Marie in August 1921, outflows from Lake Superior have been completely regulated in accordance with the Orders of Approval of the International Joint Commission issued May 26 and 27, 1914.[29]

Requirements are that the works be operated to maintain the monthly mean levels of Lake Superior as nearly as possible between elevations 602.1 and 603.6 feet above mean tide at New York (the elevations referred to in IGLD [1955] are 600.5 and 602.0 feet). Such operations must not hinder navigation.

TABLE 11–30 Canadian Diversions of the Great Lakes

From	To	Description	Annual Average (cfs)	Period Covered
Albany River-Hudson Bay Basin	Lake Superior Basin	Ogoki-Long Lake Projects[1]	6,110	1959-1968
St. Marys River	St. Marys River	Great Lakes Power Canal[2] (Power Diversion)	23,000 18,000[5]	1959-1968 1970-present
		Canadian Navigation Canal	100	1959-1968
Lake Huron	Thames River, Lake St. Clair Basin	City of London, Ontario Water Intake	30 cfs daily average maximum capacity 85 cfs	
Lake Erie	Lake Ontario	Welland Canal and DeCew Falls Power Plant[3]	7,290	1959-1968
Niagara River	Niagara River	Sir Adam Beck Powerhouse	55,800	1965-1968
		Canadian Niagara Powerhouse	200	1965-1968
		Toronto Powerhouse	600	1965-1968
		Ontario Powerhouse	1,000	1965-1968
St. Lawrence River	St. Lawrence River	St. Lawrence International Powerhouse	(shown on U.S. diversion list)	
		Raisin River[4]	25 cfs for 100 days/year	

[1]Diversions of water from the Albany River basin, a part of the Hudson Bay watershed, through the Long Lake and Ogoki projects in Canada.

[2]Included approximately 5,000 cfs for Abitibi Paper Company for mechanical power purposes.

[3]Water from Lake Erie reaches Lake Ontario by way of the Welland Canal and the tailrace of DeCew Falls hydroelectric power plant, located three miles west of the Welland Canal. The DeCew Falls plant draws its water from the Welland Canal.

[4]Purpose is for "stock watering," recreation and for fish and wildlife in the summer. The Raisin River Conservation Authority is to reimburse Hydro-Electric Power Commission of Ontario for loss of power revenue at Saunders Generating Powerhouse.

[5]Starting in May 1970 installation of an 8,000 hp electric motor eliminated the use of direct hydropowered grinders which for many years had served the same purpose; net result is a decrease in water requirements. Abitibi Paper Company canal was modified in May 1972 to restore former discharge capacity on an as-needed basis when level is high on Lake Superior.

TABLE 11–31 Future Planned or Proposed U.S. Diversions of the Great Lakes

From	To	Description	Annual Average (cfs)
Mississippi River	Lake Michigan Basin	Wisconsin River to Fox River[1]	
		Little Calumet River, Indiana and Illinois[2]	
Lake Erie	Lake Ontario	Lake Erie-Lake Ontario Canal[3]	2,040

[1]Channel connection exists and minimal quantities may be used to improve water quality conditions on Fox River during low flow periods.

[2]Flood control dam and pump stations to re-divert to Lake Michigan this amount which is a part of the present Chicago diversion while maintaining by pumping continual flow throughout the year in the Little Calumet River.

[3]Based on 4 locks each with an 80 foot lift. The diversion through the Welland Canal may be less in 1985 than it is at the present time.

FIGURE 11-20 St. Clair River Compensation Works—Tentative Location of Sills

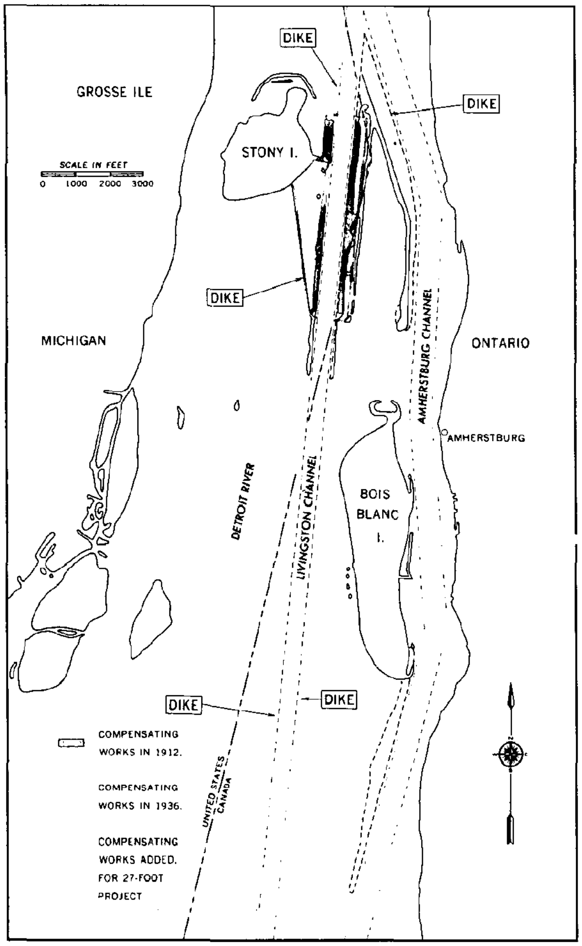


FIGURE 11–21 Detroit River Compensation Works

The Orders further provide that the regulation plan shall cause no monthly mean elevation greater than the maximum monthly mean actually experienced in any year of recorded high water (greater than 602.0 IGLD, [1955]). Whenever the monthly mean level of the Lake is less than 600.5 IGLD (1955), the total discharge permitted shall be no greater than that which it would have been at that low stage and under the discharge conditions which prevailed before 1887.

To guard against unduly high stages of water in the lower St. Marys River, the excess discharge at any time over and above that which would have occurred at a like stage of Lake Superior prior to 1887 shall be restricted so that the elevation of the water surface immediately below the locks shall be no greater than 582.9 IGLD (1955). The operation of the river control works and the power canals—i.e., the flows in the canals—are supervised directly by the International Lake Superior Board of Control established by the Commission in accordance with the terms of its Order.[29]

The control structure in the St. Marys River (above the rapids at Sault Ste. Marie) consists of 16 steel gates, each 51 feet long and built between concrete and masonry piers approximately eight feet wide (Figure 11–22). It was completed in 1916 except for a closure of flow between the southern end of the gated structure and other works situated in the river along the United States shore. The flow through this 250-foot section remained uncontrolled until the closure was completed in August 1921. A general plan of the regulatory works is shown in Figure 11–23 and includes distribution of flow (estimated diverted amount through the power and navigation canals) for September 1970.

The plan first used in actual regulation of any of the Great Lakes was developed in 1916 for controlling the outflows of Lake Superior. This plan, sometimes referred to as the Sabin Rule, provided a tentative basis for operating the regulating gates before closure of the section south of the structure, and its use was continued after such closure until 1941.

The rule was used merely as a guide. A plan developed for the Board of Control by the U.S. Lake Survey and designated Rule P–5[44] replaced the Sabin Rule and was used until 1951. Rule P–5 increased minimum flows for power to the greatest extent possible without detriment to navigation.

A plan designated the Rule of 1949[44] was developed primarily in recognition of the increased supplies of water to Lake Superior coming from the Hudson Bay watershed through the Long Lake and Ogoki projects. The Rule of 1949 has been used since 1951, but was modified in 1955 to improve results.

The Rule of 1949, and since 1955, the Modified Rule of 1949,[44] have been followed closely. The most extensive departure from the rule was in 1964 when Lake Superior had a favorable supply-storage, while the levels of Lakes Michigan-Huron were setting record lows. Beginning in April 1964, releases of water from Lake Superior were increased above those called for by the rule. Increased outflows were continued throughout the year, averaging approximately 8,500 cfs larger, from April through December 1964, than rule outflows.

The International Joint Commission was kept informed of the situation and approved the Control Board's recommendation of June

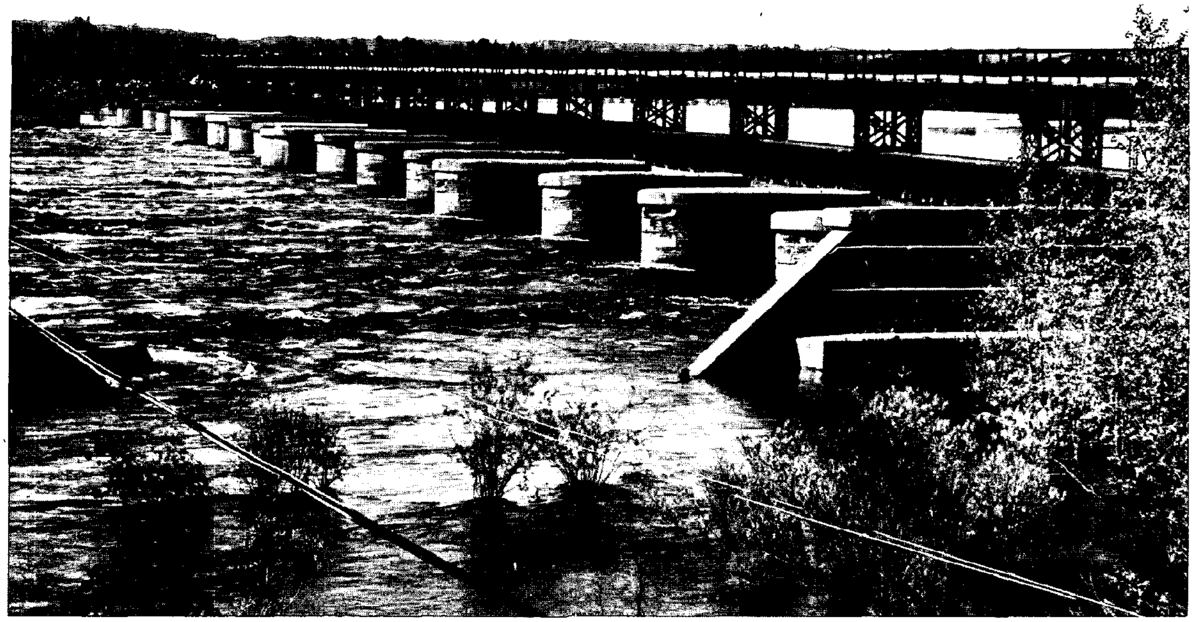


FIGURE 11–22 Lake Superior Control Structure—St. Marys River at Sault Ste. Marie, Michigan, Looking Upstream

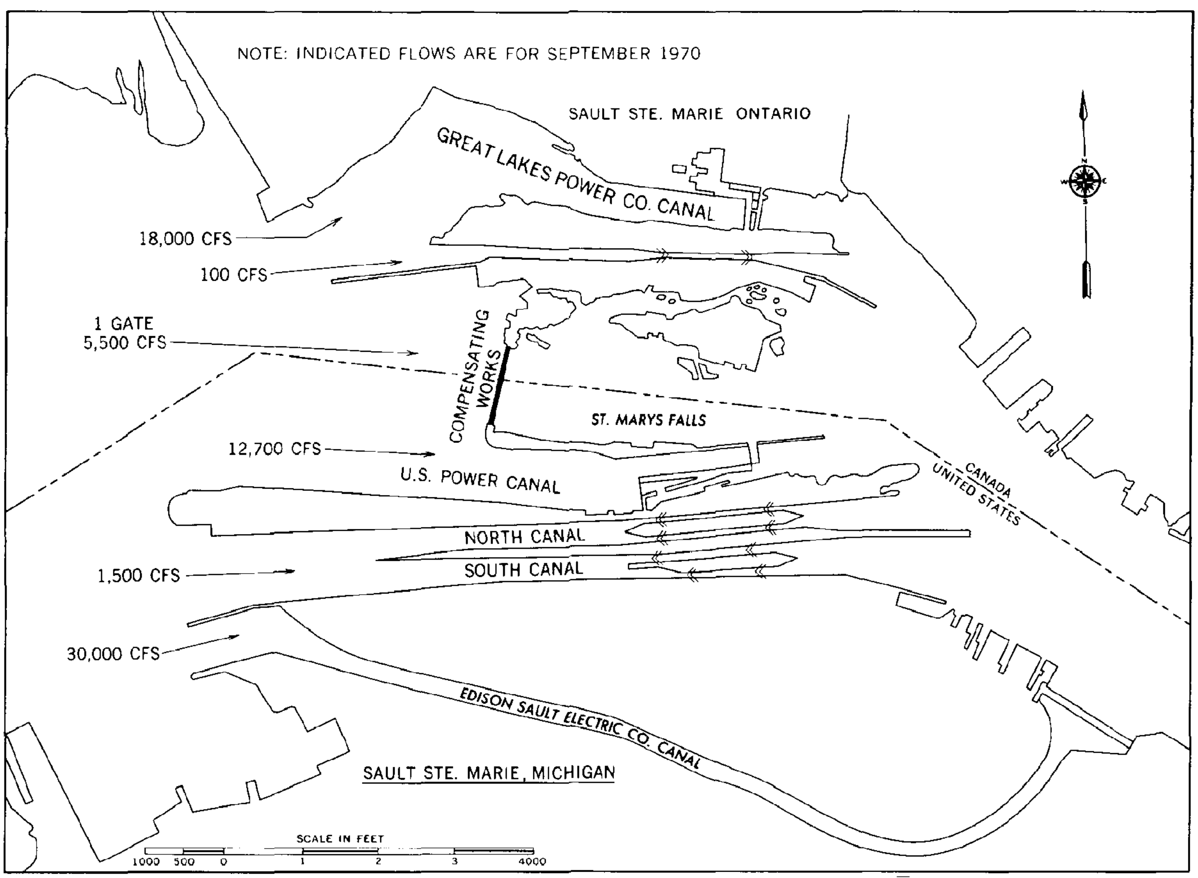


FIGURE 11–23 Distribution of Flow for the St. Marys River

19, 1964, that increased releases of 10,000 cfs over the rule amounts be continued as long as the supplies to Lake Superior remained favorable, and the large differential between the Lake Superior and Lakes Michigan-Huron levels continued.

Rule outflows depending on levels of Lake Superior under the Modified Rule of 1949 are shown in Figure 11–24. Rating curves for the regulatory structure are in Figure 11–25. Stage-duration curves for all months and for the open-water season are shown in Figures 11–26 and 11–27 for the period 1900–1968. They are adjusted to fixed diversion, outlet, and other conditions:

(1) constant diversion of 5,000 cfs into Lake Superior from Long Lake and Ogoki projects

(2) Lake Superior regulated in accordance with the September 1955 Modified Rule

(3) constant diversion of 3,200 cfs out of Lake Michigan at Chicago

(4) 1933 preproject outlet conditions for Lake Huron

(5) constant diversion of 7,000 cfs through Welland Canal from Lake Erie to Lake Ontario

(6) 1953 outlet conditions for Lake Erie

(7) Lake Ontario regulated in accordance with Plan 1958–D

6.5 Regulatory Works in the St. Lawrence River

The regulation of Lake Ontario began in April 1960 as part of the operation of the St. Lawrence Seaway and Power Project. Principal regulatory works are shown in Figure 11–28.

The Robert Moses-Robert H. Saunders Power Dam extends 3,300 feet across the St. Lawrence River from Barnhart Island, New York to Cornwall, Ontario. Normally the full discharge of the river flows through the power dam. Upstream of the power dam, the river formerly flowed in two channels. Now the channel north of Barnhart Island is closed by the power dam. The channel south of the island is closed by the Long Sault Dam. This dam is a curved axis concrete structure 2,960 feet long with thirty spillway gates. If required, the entire river flow could pass through the Long Sault gates. The power pool extends 25 miles upstream from the Moses-Saunders power dam to Iroquois Dam, a concrete structure 1,800 feet long at the upstream end of what is known as Lake St. Lawrence. Iroquois Dam was built to provide flexibility on project operations and, if necessary, can control the outflow from Lake Ontario.

6.6 Lake Ontario Regulation

Lake Ontario regulation follows the International Joint Commission's Orders of Approval dated October 29, 1952, and July 2, 1956,[29] and the International St. Lawrence River Board of Control directly supervises it. The Orders provide that the Lake is to be regulated within a range of monthly mean stages as nearly as possible during the navigation season. On IGLD (1955) these stages are from elevation 242.8 feet to elevation 246.8 feet. The Orders provide that certain additional requirements are to be met. The Order of July 2, 1956, lists eleven operating criteria which are quoted below with elevations converted to IGLD (1955):

> Criterion (a): The regulated outflow from Lake Ontario from April 1 to December 15 shall be such as not to reduce the minimum level of Montreal Harbor below that which would have occurred in the past with the supplies to Lake Ontario since 1860 adjusted to a condition assuming a continuous diversion out of the Great Lakes basin of 3,100 cubic feet per second at Chicago and a continuous diversion into the Great Lakes basin of 5,000 cubic feet per second from the Albany River basin.
>
> Criterion (b): The regulated winter outflows from Lake Ontario from December 15 to March 31 shall be as large as feasible and shall be maintained so that the difficulties of winter operation are minimized.
>
> Criterion (c): The regulated outflow from Lake Ontario during the annual spring break-up in Montreal Harbor and in the river downstream shall not be greater than would have occurred assuming supplies of the past as adjusted.
>
> Criteriod (d): The regulated outflow from Lake Ontario during the annual flood discharge from the Ottawa River shall not be greater than would have occurred assuming supplies of the past as adjusted.
>
> Criterion (e): Consistent with other requirements, the minimum regulated outflows from Lake Ontario shall be such as to secure the maximum dependable flow for power.
>
> Criterion (g): Consistent with other requirements, the levels of Lake Ontario shall be regulated for the benefit of property owners on the shores of Lake Ontario in the United States and Canada so as to reduce the extremes of stage which have been experienced.
>
> Criterion (h): The regulated monthly mean level of Lake Ontario shall not exceed elevation 246.77 with the supplies of the past as adjusted.
>
> Criterion (i): Under regulation, the frequency of occurrence of monthly mean elevations of approximately 245.77 and higher on Lake Ontario shall be less than would have occurred in the past with the supplies of the past as adjusted and with present channel conditions in the Galop Rapids Section of the St. Lawrence.
>
> Criterion (j): The regulated level of Lake Ontario on April 1 shall not be lower than elevation 242.77. The regulated monthly mean level of the lake from April 1

to November 30 shall be maintained at or above elevation 242.77.

Criterion (k): In the event of supplies in excess of the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to the riparian owners upstream and downstream. In the event of supplies less than the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to navigation and power interests.

Preliminary studies made for the Commission developed a number of plans for regulating Lake Ontario. The results, evaluated by engineering consultants, became the basis for establishing the range of stage for regulation of the Lake and the operating criteria. The Corps of Engineers helped to develop these plans, documented in the International Lake Ontario Board of Engineers final report.[22]

The first plan used in the regulation of Lake Ontario, Plan 1958–A, was developed by the International St. Lawrence River Board of Control on the basis of the approved range of stage and criteria. Plan 1958–A was used by the Board of Control from April 1960 until January 1962, when Plan 1958–C[44] replaced it.

Plan 1958–C reduced the frequency of low flows at Montreal, and the revised plan, Plan 1958–D, became effective in October 1963. The Corps of Engineers participated in developing these plans. The studies, one for each plan, are documented in Board of Control reports to the International Joint Commission, dated May 1958, October 1961, and July 1963, respectively.

Regulation Plan 1958–D[44] is the current plan approved for the Board's use in consultation with the Power Authority of the State of New York, the Hydro Electric Power Commission of Ontario, and other interests concerned with compliance with the criteria and other requirements of the Orders of Approval. The most extensive departure from the plan was during the winter of 1964–65, when outflows from the Lake were reduced as much as 25,000 cfs below the plan minimum. This was to prevent lake levels from dropping excessively in winter and therefore to increase the amount of Lake Ontario storage available to benefit all water uses.

An outflow duration curve for Lake Ontario under Regulation Plan 1958–D is shown in Figure 11–29. Stage-duration curves for all months are shown in Figures 11–30 and 11–31.

6.7 Increased Water Level in Lake Ontario Attributable to Gut Dam

In 1903 the Canadian Government constructed the Gut Channel Dam. The works crossed the International Boundary in the upper reaches of the St. Lawrence River in order to improve navigation conditions (Figure 11–32). U.S. approval for the dam depended upon Canada assuming responsibility for any damage to U.S. property caused by its construction or operation. As a result of the very high water levels occurring in the Great Lakes during the early 1950s, the International Joint Commission was asked in 1952 to study the various factors affecting the fluctuation of water levels on Lake Ontario, including the effects of the Gut Dam. Studies sponsored by the Commission, including gage relationships, backwater computations, and hydraulic model, determined that the Gut Dam did increase water levels in Lake Ontario between four and five inches, depending upon the stage or discharge in the St. Lawrence River.[21] As the result of the 1951–52 high water period on Lake Ontario, U.S. lakefront property owners claimed damages resulting from the effects of the Gut Dam,[40] which was removed in January 1953.

By applying the effects of the Gut Dam (Table 11–32) to the 1951–52 hydrograph for Lake Ontario, the daily mean lake stage is increased by 0.4 foot for stage occurrences up to elevation 247.3 feet, and by amounts following a straight-line variation between 0.4 and 0.33 foot for changes in elevation between 6.1 and 8.1 feet respectively. The latter is the maximum daily mean stage in the 1951-52 period. The generalized evaluation procedures presented are based on conditions during the two-year period, 1951–52, when most of the claimed damages apparently occurred.

It is presumed that, had the Gut Dam not been in existence, similar recorded levels would have resulted, but with a mean elevation from 0.4 to 0.33 foot lower throughout the period, according to the flow conditions described above. A 1965 agreement for final disposition of U.S. lakefront property owners' claims against Canada provided for establishment of a three-member international arbitral tribunal. The Lake Ontario Claims Tribunal of United States and Canada has disposition of claims under consideration.

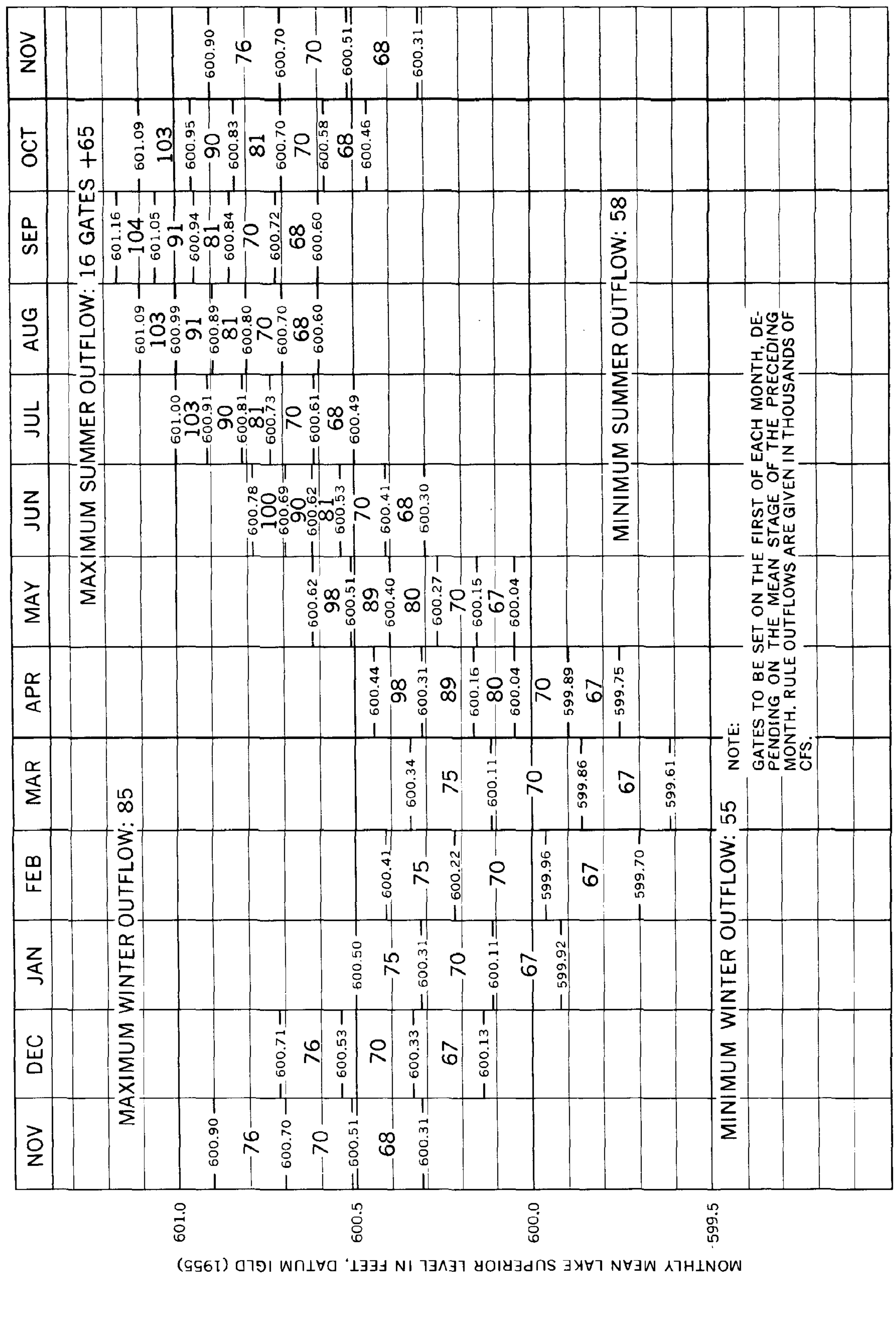


FIGURE 11–24 Regulation of Lake Superior—Modified Rule of 1949

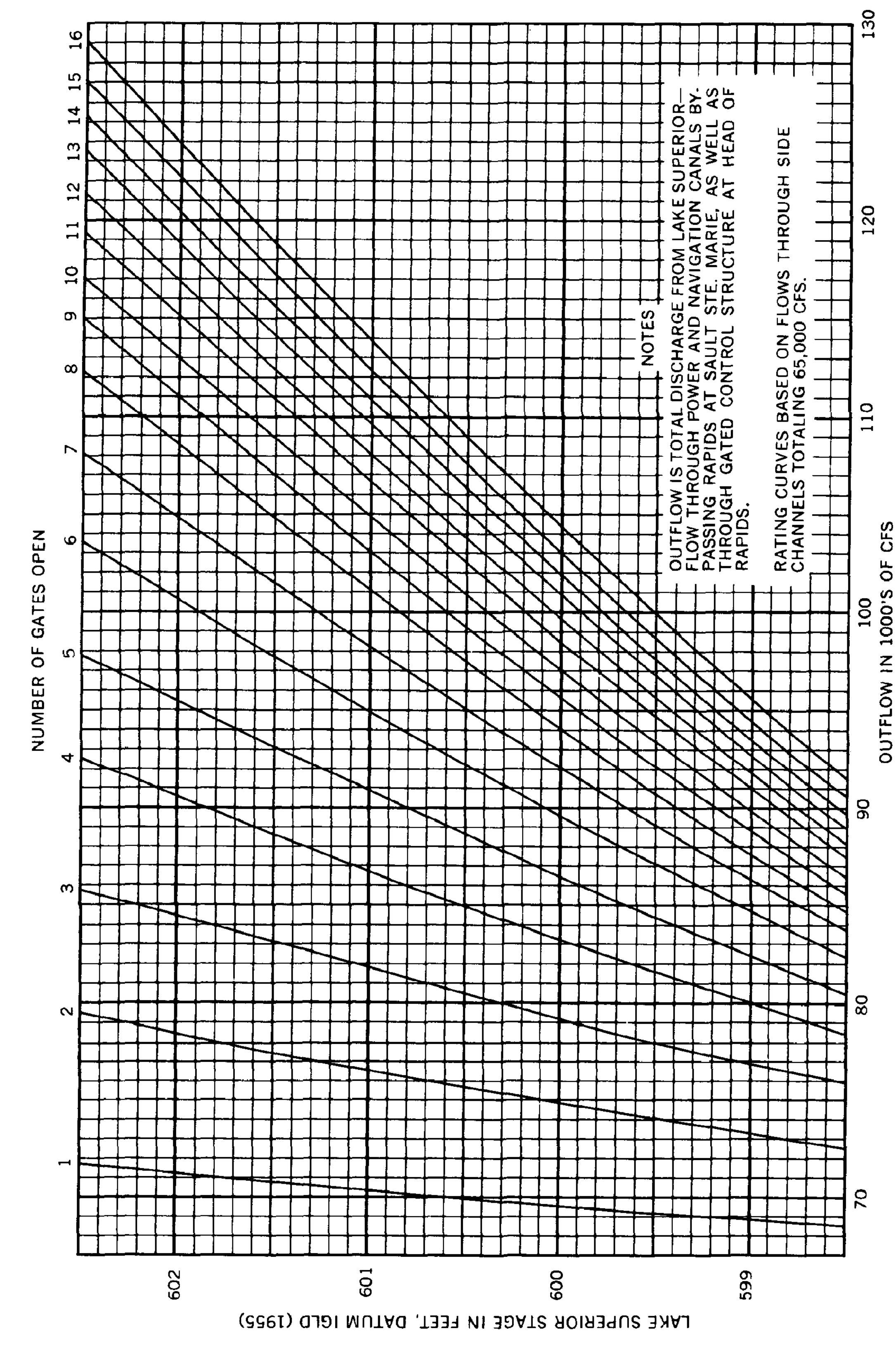


FIGURE 11-25 Lake Superior Rating Curves for Various Gate Openings

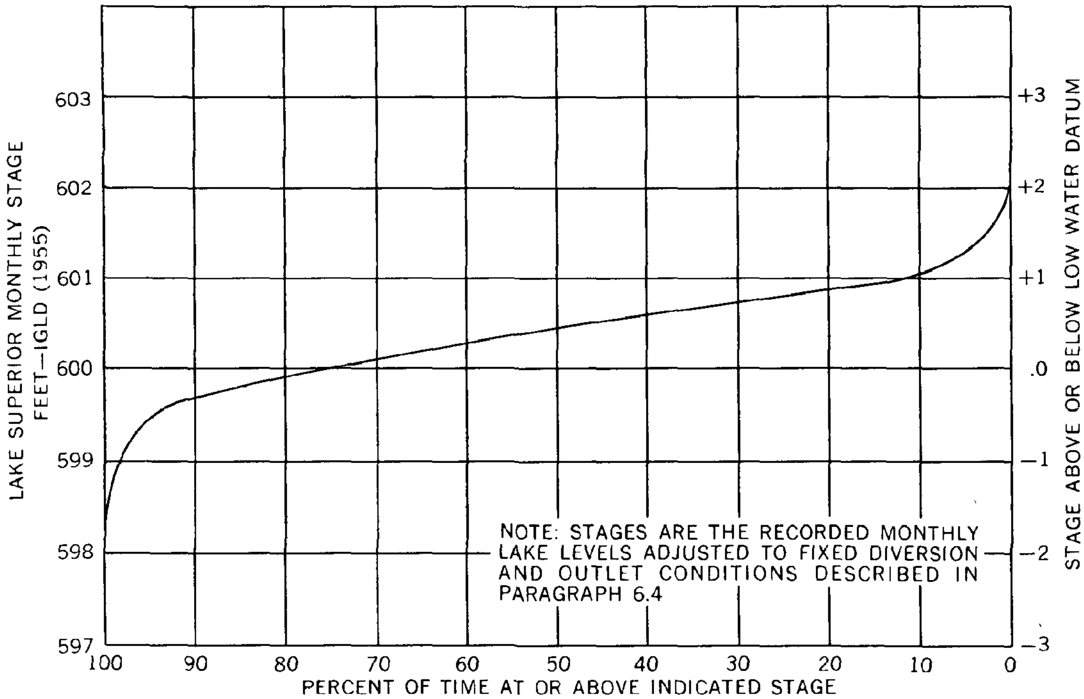


FIGURE 11–26 Lake Superior Stage Duration for All Months 1900–1968

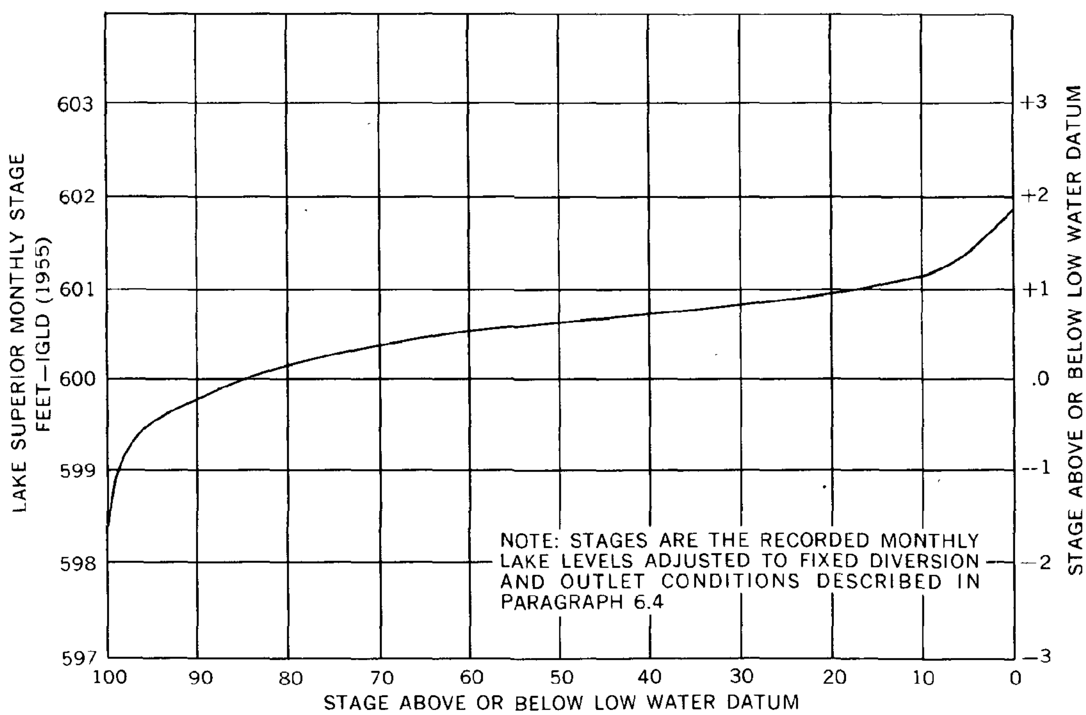


FIGURE 11–27 Lake Superior Stage Duration for April-November 1900–1968

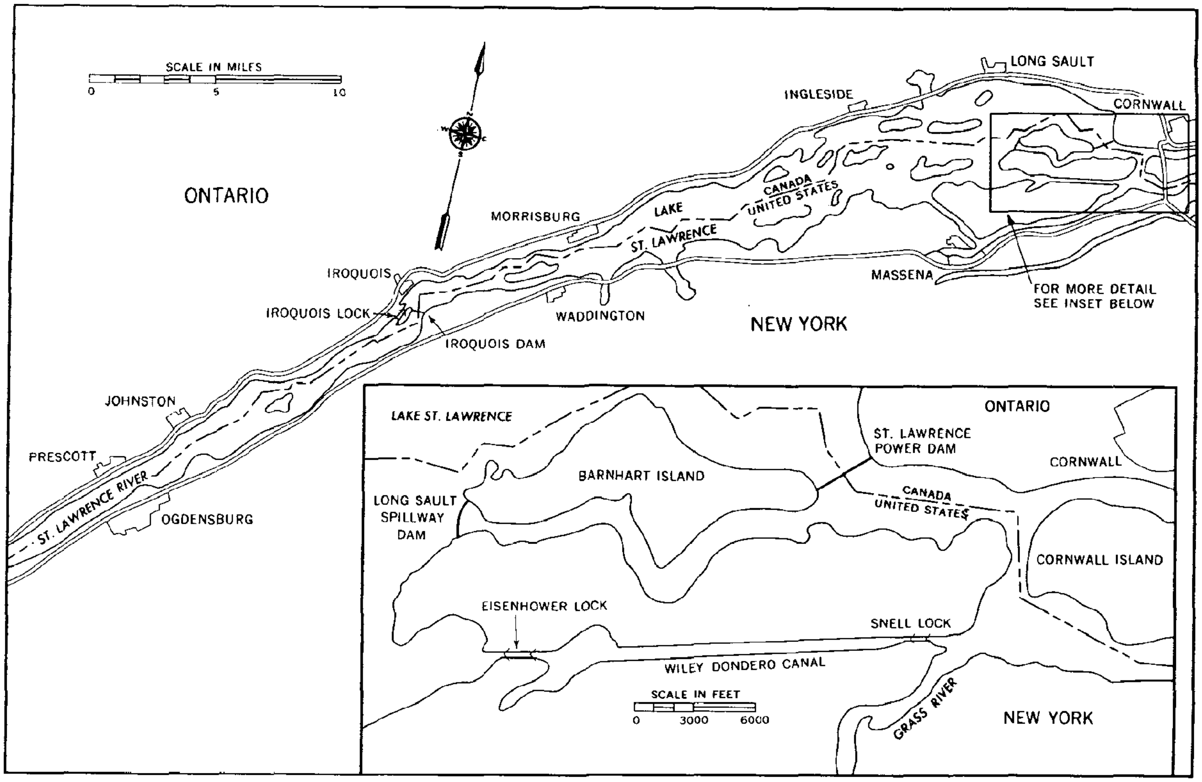


FIGURE 11-28 Lake Ontario Regulatory Works

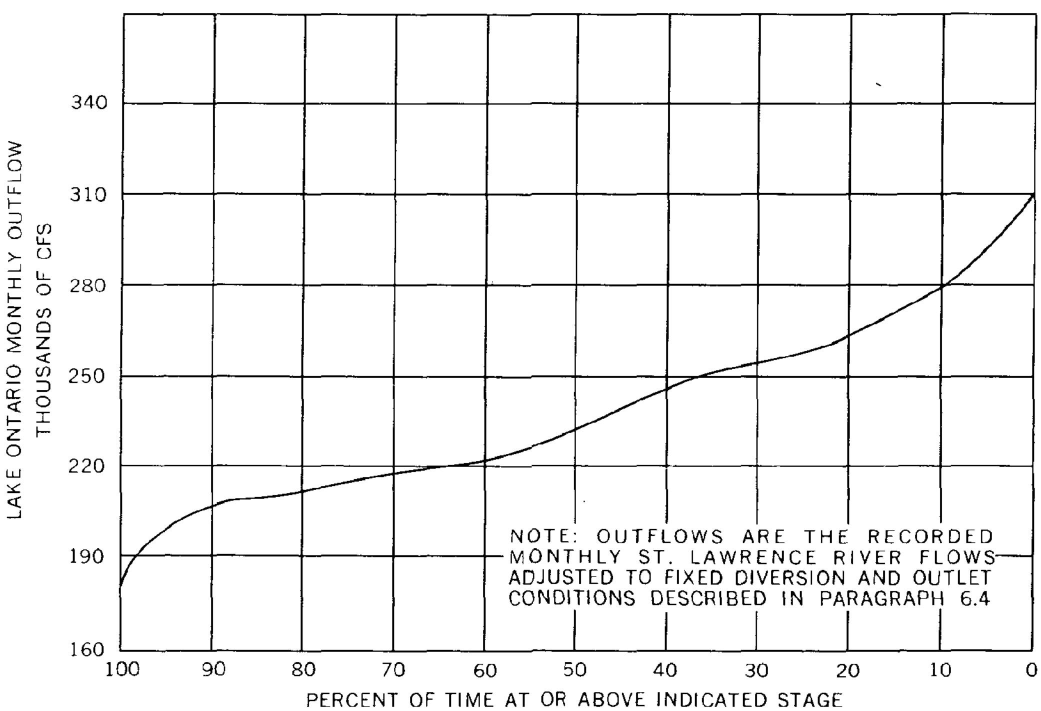


FIGURE 11-29 Lake Ontario Outflows for All Months 1900–1968

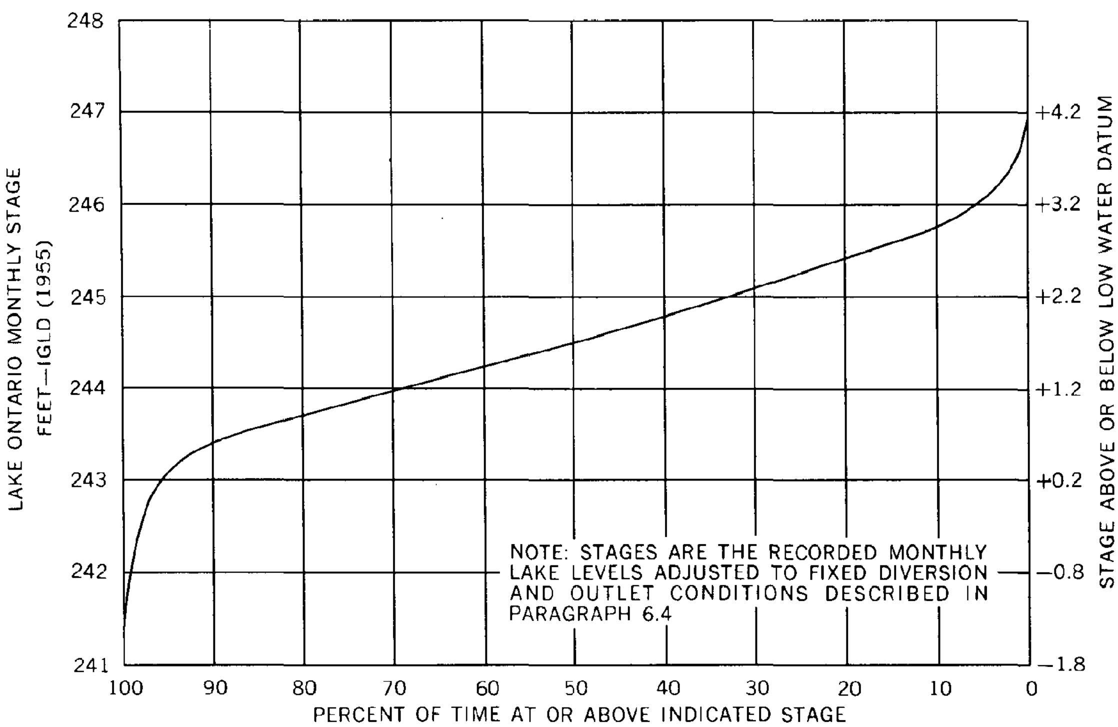


FIGURE 11–30 Lake Ontario Stage Duration for All Months 1900–1968

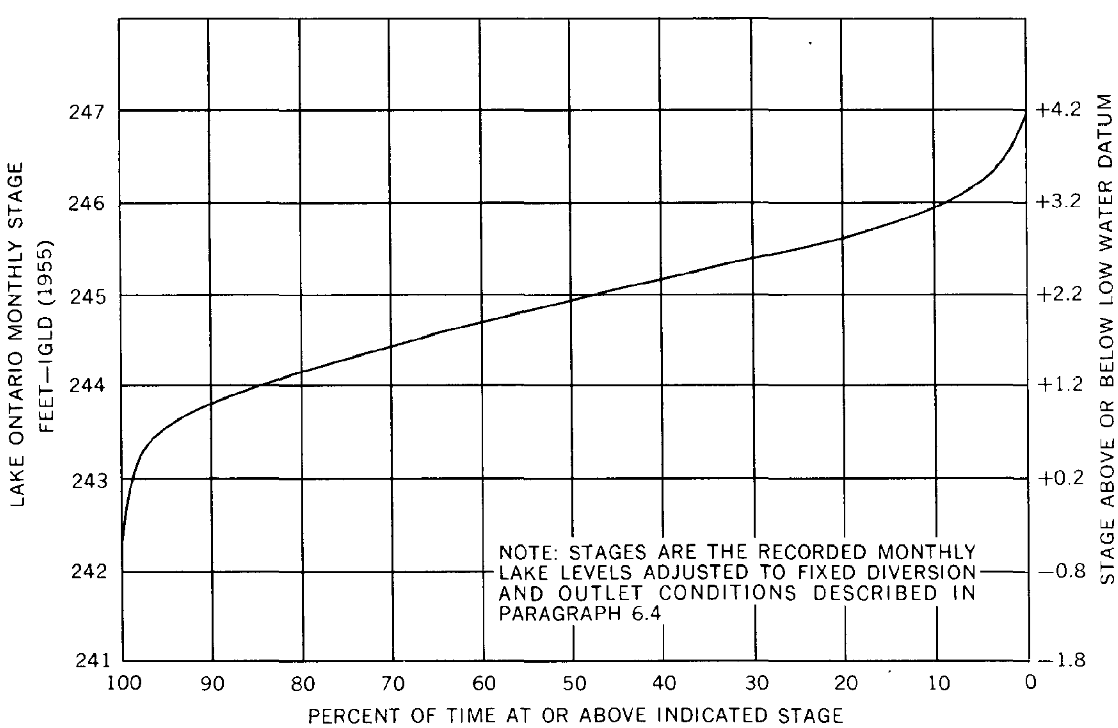


FIGURE 11–31 Lake Ontario Stage Duration for April-November 1900–1968

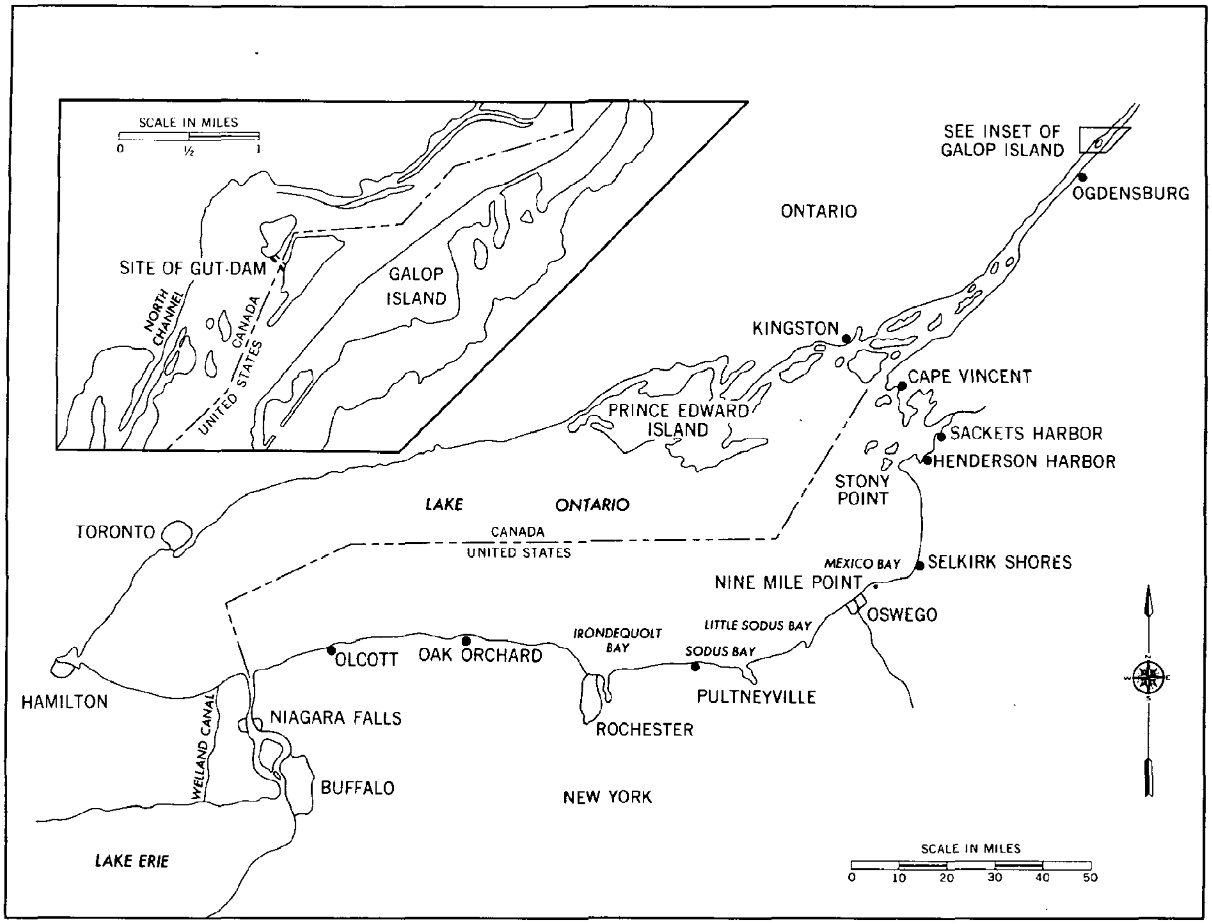


FIGURE 11–32 Lake Ontario with Inset of Gut Dam Site

TABLE 11–32 Summary of Effects of Gut Dam on Lake Ontario Water Levels

	River Discharge (cfs)			
	180,000	240,000	267,000	310,000
Lake Stage at Oswego, N.Y. (1935 Datum)	+1.80	+4.48	+6.10	+8.10
Effect of Dam, in feet	+0.40	+0.41	+0.40	+0.33

6.8 Effects of Factors on Ranges

The recorded high of Lake Superior in 1876 occurred prior to appreciable effect on the levels by artificial factors. The recorded low of the Lake occurred after the outflows were fully regulated, but before diversion of water into the Lake augmented supplies. The minimum level was reached in 1926, and was approximately 0.2 foot higher than it would have been with the natural outlet. The recorded range of levels is increased by 0.2 foot to approximate the range that would have occurred naturally.

The recorded Lakes Michigan-Huron high level of 1886 also occurred prior to appreciable artificial influences on the levels. A review of the recorded lows of February 1926, March 1934, and March 1964, indicates that, with adjustments for artificial factors, the low of March 1964 is still the lowest level of record.

As of March 1964, the net effects of the Long

Lake-Ogoki, Chicago, and Welland diversions upon Lakes Michigan-Huron levels were practically zero. At that time, the effect of Lake Superior regulation on Lakes Michigan-Huron levels was also negligible. Engineers estimate the 1964 recorded low to be an all-time low because of rainfall shortages. Channel changes in the St. Clair-Detroit Rivers were not a factor.

Based on the estimate given in the Joint Board of Engineers' 1926 report,[24] the total net effect on Lakes Michigan-Huron levels of channel changes in this river system prior to 1926 was a lowering of 0.6 foot. The Corps of Engineers estimates the uncompensated effect of dredging for the 25-foot and the 27-foot navigation projects in the 1930s and 1960s was a lowering of 0.59 foot, making a total lowering effect to date of approximately one foot. The recorded Lakes Michigan-Huron low should be increased approximately one foot and the recorded range decreased by that amount in order to approximate the range that would have occurred naturally.

A comparison of the recorded levels of Lake Erie with the values adjusted for artificial factors indicates that the adjusted maximum and minimum levels would occur in the same months as the recorded high and low values.

The adjustment made to the recorded high of May 1952 to compensate for the net effect of artificial factors is estimated to be +0.1 foot; for the low of February 1936 it is estimated to be +0.5 foot. Therefore, one should decrease the recorded range of Lake Erie levels by 0.4 foot in order to approximate the range that would have occurred without the artificial factors.

The International Lake Ontario Board of Engineers in its Final Report[22] to the International Joint Commission determined that artificial factors caused the June 1952 high on Lake Ontario to be approximately 0.5 foot higher than without these factors, and caused the November 1934 low to be approximately 0.3 foot lower than without these factors. However, with the adjustments applied the recorded level of May 1870 (247.74) would become the high. So far, the adjusted value for November 1934 would be the low of the past century. The range given by the recorded levels is therefore reduced by 0.7 foot in order to approximate the range that would have occurred naturally.

A comparison of the recorded ranges with the approximate ranges that would have occurred naturally appears in Table 11–33. The term "basis of comparison" is frequently applied to the recorded data which have been adjusted to constant diversion and outflow regimen conditions.

TABLE 11–33 Comparison, Recorded Ranges with Approximate Natural Range of Great Lakes Levels, 1860–1970 (in feet)

	Recorded Range	Approximate Natural Range	Increase in Range[1]
Superior	3.9 feet	4.1 feet	-0.2 feet
Michigan	6.6 feet	5.6 feet	1.0 feet
Huron	6.6 feet	5.6 feet	1.0 feet
Erie	5.3 feet	4.9 feet	0.4 feet
Ontario	6.6 feet	5.9 feet	0.7 feet

6.8.1 Other Factors

Ice retardation and consumptive uses of water are other factors to be considered. Although ice retardation is a natural occurrence, current and future lake regulation plans include flow limitations to alleviate ice effects. These limitations result in a further artificial factor affecting lake levels. Further details on ice retardation have been provided in Section 5.

6.8.2 Ice Retardation

The only limitation imposed in the regulation of Lake Superior is that lake outflow be limited to a maximum of 85,000 cfs from early December through April, because of ice conditions in the St. Marys River.[44] Studies by the International St. Lawrence River Board of Control for the regulation of Lake Ontario impose maximum flow in critical reaches of the St. Lawrence River during February and March to meet winter operating conditions.

Ice booms are now installed each winter in the Galop reach of the St. Lawrence River. Data on ice conditions and winter flows are collected for each operating winter. These data are summarized in the April semiannual progress reports of the International St. Lawrence River Board of Control and the International Joint Commission. Annual reports on winter operations are prepared jointly by the Hydro Electric Power Commission of Ontario and the Power Authority of the State of New York.[34] Winter operations under the approved regulation plan have been successful to date.

6.8.3 Lake Erie and the Niagara River

Ice conditions on the Niagara have materially restricted the Lake Erie outflow for short periods. In connection with the use of Niagara River water for power, the Hydro Electric Power Commission of Ontario and the Power Authority of the State of New York jointly determine methods to aid the passage of ice at points where water is diverted from the river by the power entities.

Prior to the 1964–65 ice period,[3] control engineers built a Commission-approved ice boom in Lake Erie at the head of the Niagara River to aid in the formation and maintenance of the ice arch at the head of the river, and thus reduce the adverse effects of ice on river levels and flows. Experiences with ice booms are satisfactory.[3] The retardation of flow from ice jams is reduced considerably by the ice boom and the ice-escape channel near the power intakes.

In the long run, it is estimated that any lowering of Lake Erie levels will be slight. Long-term analysis of Lake Erie levels will be made as data are assembled.

Water transportation interests want the navigation season lengthened. Use of ice-breakers, air bubblers, heating devices, or other means of reducing ice formation for keeping channels open for the benefit of navigation could also affect outflows and levels of the Lakes, and could act as an artificial lake level control.

6.8.4 Consumptive Use of Water

Waters of the Great Lakes are used along the lakeshores and in the land drainage areas for many purposes, but the total effect on water quantities of the Lakes has been relatively small. The types of uses and amounts of water completely withdrawn from the system may be inferred from data in other appendixes. An assessment of these uses is presented later in this appendix. Previously published estimates of consumptive losses of water were described in a report by the Regulation Subcommittee, International Great Lakes Levels Working Committee.[18] This report showed that 1965 consumptive water use within the Great Lakes Basin totaled 2269 cfs, and that 55 percent of it was consumed in the Lakes Michigan-Huron basins and 30 percent in the Lake Erie basin. Based upon these consumptive rates, the levels of Lakes Michigan-Huron and Lake Erie have been lowered more than one inch. The levels of Lakes Superior and Ontario are maintained through regulation, but this consumptive use has reduced the average outflow of Lake Ontario by nearly one percent.

Section 7

HISTORY AND PRESENT STATUS OF REGULATION AND REGULATION STUDIES

7.1 General

In their unregulated state, variations in the levels and outflows of the Great Lakes are much smaller than they would be without the large natural storage effects inherent in their vast surface area. During the last half-century, however, many studies have considered regulating the levels of one or more of the Lakes by controlling their outflows.

Works constructed at their outlet rivers have controlled Lakes Superior and Ontario somewhat in this way. An international study is in progress to determine whether further regulation of one or more of the Great Lakes is in the best interests of Canada and the United States.

Many of the earlier regulation studies were made during periods of low lake levels, and the primary objective was to improve depths for navigation. In general, levels would have been raised by adoption of the suggested regulation plans. A few of the earlier studies on Lakes Superior, Erie, and Ontario increased minimum outflow rates to improve dependable flows for hydropower. Except in certain studies on the regulation of Lakes Superior and Ontario, none has specifically planned a reduction of high lake stages.

The earlier lake regulation studies were based on considerably shorter lake level and outflow records than those existing today, and therefore did not include the broader objectives of contemporary investigations. The development of analysis techniques during the past decade, including application of automatic data processing and computer techniques, facilitates more thorough investigation. However, earlier studies should not be overlooked. Subsequent studies on the regulation of Lakes Superior and Ontario, and the unilateral investigation completed by the U.S. Army Corps of Engineers in 1965 also provide valuable contributions to evaluating the problem.

Under present and prospective developments in the Great Lakes area, lake regulation plans must consider the effects of such regulation on many interests.

7.1.1 Purposes

The basic purposes of this discussion are to review the regulation studies of the past, to evaluate the application of methods and plans with respect to regulation of Lake Superior and Lake Ontario, and to bring out the international nature of controlling the levels of the Great Lakes.

7.2 Previous Studies

There have been about 30 studies relating to the regulation of one or more of the Great Lakes.[27] This discussion specifically mentions 12. Six are investigations to demonstrate the feasibility of lake regulation; three are plans already used in regulating Lake Superior; and three are plans used in regulating Lake Ontario.

7.2.1 Feasibility Studies

A report on Regulation of Lake Superior dated December 30, 1911, by Noble and Woodard, consulting engineers for the Michigan Lake Superior Power Company, devised a rule for regulation of the Lake with increased diversions of water for power operation purposes at Sault Ste. Marie. The study envisioned a control structure differing from that finally constructed, and its regulation plan was never used. The tabulation of Lake Superior "supply factors" presented in this report is still used and extended monthly.

A report on Diversion of Water from the Great Lakes and Niagara River was transmitted to the Speaker of the House of Representatives on December 7, 1920. A discussion of lake regulation as a means of restoring navigation depths on the Lakes refers to an earlier report by the Deep Waterways Board,[31] dated June 30, 1900, which presented a plan for regulating Lake Erie.

In 1926 John R. Freeman[13] completed a report for the Chicago Sanitary District on *Regulation of the Great Lakes and Effects of Diversions* by Chicago Sanitary District. Among other things, the report suggests the possibility of lake regulation which would raise both the high and low levels appreciably. Raising the high levels as suggested would be unacceptable under present conditions.

In March 1952, the Special Projects Branch of the Canadian Department of Transport published a report[5] on regulation of outflows and levels of Lake Ontario. The plan is in the form of a rule curve and was designed to meet eight specific requirements. Later revisions to the basic data made this plan obsolete.

In March 1957 the International Lake Ontario Board of Engineers submitted a report[22] on regulation of Lake Ontario to the International Joint Commission. The report documents regulation studies the Board had made. These studies also developed governing criteria as a guide in the further development of regulation plans for Lake Ontario.

In December 1965 the U.S. Army Corps of Engineers issued a report entitled "Water Levels of the Great Lakes, Report on Lake Regulation." It presented study plans developed by the Corps of Engineers, and a summary of other pertinent information and data. This report provided considerable discussion of the physical and economic aspects of the Lakes, knowledge necessary in defining the present-day problem. Experience gained in operating plans or rules for the actual regulation of Lakes Superior and Ontario has also provided much invaluable information about lake regulation.

7.2.2 Lake Superior Regulation

Since completing the control works on the St. Marys River at Sault Ste. Marie in August 1921, the outflows from Lake Superior have been subject to complete control. The Lake is regulated, in accordance with the Orders of Approval of the International Joint Commission issued May 26 and 27, 1914,[29] in reply to applications for authorization of diversions of water around the rapids for production of power. The Orders provide that the works be so operated as to maintain lake levels within a specified range and not to interfere with navigation. Further, they provide safeguards against extremely high and low regulated lake levels, and high levels on the St. Marys River. The International Lake Superior Board of Control, established by the Commission in accordance with the terms of its Order, directly supervises the operation of the river control works and the amount of the diversions. Details on the regulation plans used for Lake Superior are found in Section 6.

7.2.3 Lake Ontario Regulation

Regulation of Lake Ontario began in April 1960 in accordance with the International Joint Commission's Order Approval of October 29, 1952, and the Supplementary Order of July 2, 1956.[29] It is now under the direct supervision of the Commission's International St. Lawrence Board of Control.

The Orders provide that the Lake is to be regulated during the navigation season within a certain range of levels, and that it should meet certain additional requirements relating to downstream interests, power interests, and other Lake Ontario interests.

7.3 Lake Regulation

The word regulate implies a capacity, through man-made adjustable works, for discretionary control of outflows. Regulating the levels and flows of the Great Lakes and their outlets involves applying prescribed rules to the management of the available water supply, modifying extremes of levels and flows, and narrowing or extending the range between high and low.

Interests affected by variations in the levels and outflows of the Great Lakes are considered in three general categories: shore property interests, navigation interests, and power interests.

Shore property interests are all public and private lands and developments along the shores. These involve large and small but important types of water use. Swimming, boating, fishing, hunting, and all associated amenities of beach-resort life and recreation form large and rapidly expanding interests. Domestic water supply and sanitation are highly important. Port facilities adequate for the transportation and refuge requirements of waterborne navigation are essential. Scientific methods of crop production are increasing water demands. The heavy industrialization in the Great Lakes Basin is increasing the demands for fresh water for processing and cooling.

Navigation interests are concerned about the water problems of commercial shipping through the Lakes and connecting channels. The related problems of recreational boating are also included in this category. Power interests involved are the hydroelectric power development which utilize outflows from the Lakes.

The growth of all these uses compounds the need for measures to minimize the effects of droughts and floods. All the interests have problems associated with the range of levels and flows. Some of these difficulties are associated with high water, some with low water.

High lake levels during the 1951–52 period severely damaged shore property through inundation and accelerated shore erosion. During the low lake levels of 1964, many shore installations such as marinas and water intakes became less convenient and sometimes unusable during this extreme low-water period. However, certain recreational areas where the sand beach is normally narrow had the advantages of wider foreshores during the low-water period.

The low lake levels of 1964 seriously impeded commercial navigation and restricted to some extent the areas where recreational craft could be used. During the 1964 navigation season, when the levels of Lakes Michigan and Huron were approximately one foot below Low Water Datum and the available channel depths correspondingly lessened, the cargo-carrying capacity of the Great Lakes fleet was materially reduced. There are many vessels of the fleet that can load to full draft only when the lake levels are at high stages.

Reduced lake outflows also reduce production of hydroelectric power. For example, the Niagara River flow available for power in 1964 was approximately two-thirds of the long-term average amount.

Generally, high lake levels best serve navigation. Minimum flows as large as feasible best serve hydropower, particularly during periods of high system loads. A reduction in stage ranges would best serve shore property interests since extremes of both high and low levels harm them.

Under the most favorable conditions, prescribed regulation rules cannot ensure each particular water user optimum levels and flows. Even optimum requirements of the different water uses and of individual users within a classification frequently conflict.

Prescribed rules cannot achieve the maximum needs of one interest without infringing on the existing values of other conflicting uses. However, rules applied to the water supply that Lakes receive could conceivably provide levels and flows which would bring about generally beneficial conditions without significant detriment to any interest.

7.3.1 Regulation from Outside the Basin

Most interests suffer damaging effects from cycles of low levels and flows. The damage may be reduced or eliminated by introducing excess water from other watersheds into the system. Even though such new inflows would be under control and could be shut off during periods of high natural supply in the Great Lakes Basin, it should be recognized that the effects of such added supply would remain in the lake system for years. This might contribute to a period of damaging high levels unless other measures provided compensatory outflow. Long-term weather forecasting techniques cannot be depended upon in determining safe rates of inflow.

At present there are limited diversions to and from the Great Lakes system. The net effect of the Ogoki and Long Lake diversions (more that 5,000 cfs to Lake Superior from the northern slopes of Ontario, and the outflow of 3,200 cfs from Lake Michigan drainage to the Mississippi River) represents an increase of 2,000 cfs to the system. This increase made a small and useful, though incidental, contribution to easement of the low levels problem in 1964, but, on the other hand, caused concern during the high lake levels of the early 1950s and again in 1968–69 on Lakes Superior and Erie. The effect of stopping the Ogoki diversion in 1951–52 was more psychological than physical, because water discharged into the system months before was still affecting the lower Lakes.

The lack of accurate techniques for long-term forecasting of natural water supply, the wide ranges of intensity and duration within which it is supplied, the limited outlet capacity of the connecting rivers relative to maximum rates of supply, the wide differences in areas and storage capacities of the Lakes, and the consequential slow passage of supply through the system multiply the dangers of introducing new water to the Basin. Imported water in the volumes required to cure a natural low water condition can become a serious problem if conditions suddenly and unexpectedly switch from drought to flood.

However, more sophisticated techniques of lake level regulation, involving the introduction of new sources of water supply, envision new and improved outlets whereby the net effects of the controlled additions and withdrawals suit the needs of the Lake. Investigators have suggested that excess water in Canada could be added to the Great Lakes system and that diverting supplies from the Lakes could meet a market for fresh water south of the Lakes.

Water diverted into the Basin would be carefully controlled from no inflow at all up to some maximum rate, while water diverted out of the Basin would be at an essentially constant rate equal to approximately half the maximum inflow rate. When more water was desired, the inflow would be made greater than the outflow, and when less water was needed, the inflow would be made less than the outflow. However, this plan should not obscure the basic problem which one encounters in dealing with lake levels: the assurance that one can regulate the range of natural supplies in the system so as to limit the damage which now occurs, and provide water users with a more beneficial regimen. Introduction of substantial supplies of imported water to the system would greatly complicate the study of the basic problem and should only be done with knowledge of whether such imports are feasible or available, and whether the compensatory removal would be physically and economically acceptable under modified hydrologic conditions.

An assessment of the possibilities of further regulating the uncontrolled supplies of natural resources has been carried out in the Water Levels of the Great Lakes study recently submitted to the International Joint Commission.

7.3.2 Regulation within the Basin

The control necessary to modify both the high and the low stage extremes of the natural supply in the Basin would require two facilities in the outlet of the Lake to be regulated. First, the outlet channel must be enlarged to increase its discharge capacity, so at times greater releases of water can be made from the Lake than would occur without regulation, in order to reduce high levels. Second, gated control structures can be provided so that at other times fewer releases can be made in order to raise low levels. Use of such channel enlargements and control structures in an upper Lake may accelerate or compound the need for similar facilities in the outlets of the downstream Lakes.

With the large natural variations in water supplies to the Lakes, it is not feasible to regulate any of them to a monthly mean level that would closely approximate a constant elevation. To do so by controlling the outflows would require that the lake outlet be enlarged to have a monthly discharge capacity equivalent to the largest monthly supply of water to the Lake; and further, that control works be capable of reducing the outflow to a monthly rate equivalent to the smallest monthly supply of water.

Reference to conditions in Lakes Michigan-Huron demonstrates a part of the problem. The range of monthly net supplies to these Lakes goes from a maximum amount of more than 600,000 cfs to a minimum amount of minus 100,000 cfs. A discharge rate of 600,000 cfs would require that the discharge capacity of the St. Clair-Detroit River system be enlarged nearly three times, and during the minimum supply month, the lake level would recede 0.2 foot even with the St. Clair River flow reduced to zero. To achieve an additional lowering of one foot on Lakes Michigan-Huron in a period of one month would require an increased discharge capacity of two to three times that of the existing St. Clair-Detroit River channel.

Downstream interests benefit by the fact that the waters of Lakes Michigan-Huron are not stored or released one foot at a time. The full potential must be recognized and preparations made to control the forces being redirected.

Mention was made in Section 5 of the deviation from the adopted curve for operating the control works in the St. Marys River to provide additional releases of water to Lakes Michigan-Huron during extremely low levels in 1964. As a result of this temporary increase in the supply, the levels of the Lake at the end of the 9-month period were approximately ¼ foot higher than they would have been. The effect of such an increased supply on one of the smaller Lakes would have been much greater.

The excavation and gated works or other structures that will permit the regulation will vary in amount and cost with the goals of the regulation. Major changes in flow releases in an upper Lake will require extensive and expensive works not only in its outlet river, but in each outlet downstream. This would particularly concern Lakes Michigan-Huron and the major impact that changed outflows from that large body of water could have on the much smaller areas of Lakes Erie and Ontario.

Possibilities for improved regulation exist on all of the Lakes, but the associated costs and the existing uses substantially limit the adoption of methods involving radical changes in levels and flows. In large measure, commercial and recreational water users have adjusted to the natural range of levels and flows. This suggests a limitation of regulated levels to within a previously experienced range.

In view of the proportions of the physical factors involved, the possibilities and limitations of regulating the levels and outflows of the Great Lakes are such that a feasible regulation would certainly not stabilize lake levels completely. The best method devised for defining the physical possibilities and limitations is to develop and test regulation plans based on past and likely future supplies. Technical lake regulation studies are needed to determine effects on the lake levels in order to evaluate benefits that could accrue from regulating the Lakes and to estimate the costs of providing works required in the lake outlet.

7.3.3 International Aspects

The effects of regulation of the levels and outflows of the Great Lakes cannot be other than international. Artificial control of the water supply which comes from both countries cannot be attempted without affecting the various water-use interests on each side of the international boundary. Changes in outflows and levels will, in varying degrees, benefit or harm the interests of both countries.

The framers of the Boundary Waters Treaty of 1909 foresaw and sought to alleviate the difficulties that could result from unilateral changes. Thus, the Treaty provides that no action be taken which affects the level or flow of such waters, except under prescribed procedures for coordination and agreement between Canada and the United States.

7.3.3.1 Comprehensive International Study

Within the last several decades four cycles of serious water level and flow conditions have been experienced on the Great Lakes and their outflow rivers—the high waters of 1929, the low waters of the 1930s, the high waters of the early 1950s, the extreme low waters culminating in 1964, the high water levels in 1968–69 on Lakes Superior and Erie, and the recent high levels of 1973–74 on all the Lakes, particularly Lakes St. Clair, Erie, and Ontario. Each had a devastating impact on the water economy and the water-user interests of the Great Lakes Basin. Despite such temporary setbacks, the use of the water for domestic, industrial, agricultural, navigational, power and above all, recreational purposes expanded steadily over this period. This contributed greatly to the outcry which arose over the serious low waters of the past decade.

An unprecedented climate for concerted action at all government levels in both countries existed in 1964, and it became possible and desirable to move from the important but unilateral regulation study which the U.S. Army Corps of Engineers was then completing into a broader and fully coordinated study under the aegis of the International Joint Commission, using technical data and disciplines of the two countries.

On October 7, 1964, the governments of Canada and the United States requested the International Joint Commission to determine whether measures could be taken to regulate further the levels of some or all of the Great Lakes and their connecting waters to reduce the extremes of stage which had been experienced. The governments asked the Commission to study the various factors which affect the fluctuations of these water levels and determine whether action should be taken to achieve more beneficial stage ranges and more closely control water levels for domestic use, sanitation, navigation, power, industry, flood control, agriculture, fish and wildlife, recreation, and other beneficial public purposes.

The governments requested further that if the Commission found that such changes would be practicable and in the public interest, it should indicate how the interests on both sides of the boundary would be benefited or hurt. The Commission should estimate the cost of the necessary changes, measures, and remedial works, and appraise the value of these measures to both countries, jointly and separately.

The breadth of requirements for this comprehensive assessment should be recognized. It involved colossal data assembly and analysis in various disciplines such as channel and structure design, cost and benefit determinations, allocation between conflicting interests, and value appraisals applicable to both countries involved. The services of engineers and other qualified personnel were offered by agencies of the two governments, as was technical data available during the course of the study.

7.3.3.2 Possible Future Studies

The Commission's study is confined to determination of measures to be taken within the Great Lakes Basin. The governments knew of proposals to ease the burden of low levels through diverting substantial volumes of water from other watersheds to the Great Lakes.

The alternative studies are indicated as follows: the two governments have agreed that when the Commission's report is received, they will consider whether any examination of further measures which might alleviate the problem should be carried out, including extending the scope of the present reference. Regarding such a possibility, Canadian government agencies initiated unilateral studies to determine the availability of water supplies, and the present and future needs of those supplies in their natural drainages.

7.4 Participation in Study

The International Joint Commission accepted the two governments' offers and appointed a six-man Board authorized to recruit a Working Committee and Subcommittees in the various fields of water use and disciplines essential for conducting a comprehensive and successful regulation study. The Commission arranged meetings with representatives of Provincial and State governments and was assured of the complete cooperation of their agencies in supplying data and personnel. All useful data were sent to the Commission for the active surveys as were field assessments necessary to supplement the available data.

These arrangements functioned well and contributed to the comprehensive study which is now in its final stage. Moreover, throughout this period, liaison with the Commission's Water Pollution Boards (superseded by Great Lakes Water Quality Board) has assured coordination and efficient utilization of available data and personnel.

The Lake Levels Board originally advised the Commission that it could make a comprehensive investigation and report by October 1970. Subsequent developments extended that date by three years. The Board's report was submitted to the IJC in December 1973. The lake regulation studies were organized as five separate, but interrelated investigations. Each will be discussed in subsequent subsections.

7.4.1 Regulation

Lake regulation studies consist primarily of devising regulation plans and testing the plans on past sequences of water supplies to the Lakes. Studies use this procedure to develop beneficial plans such as a desired reduction in the extremes of lake stage.

Studies have developed a means of simulating a long period of supplies whose statistical characteristics conform very closely to those of the historic supplies. However, because they cover a longer period, these simulated data provide sequences and hence a more severe test of the regulation plans than does the historic record. Other types of simulated data were also developed and used for testing purposes. To compare the efficacy of regulation plans over the simulated period, studies simulated values reflecting the effect of ice retardation on the flows through the connecting channels used for routing the simulated supplies through the Great Lakes-St. Lawrence system.

Pilot studies, completed in June 1966 on Lakes Superior and Ontario, developed preliminary regulation plans for the two Lakes using a new approach that emphasized the probable water supplies. The studies tested these plans on both the historic and simulated supply sequences. Since that time the probabilistic approach has been used to develop preliminary plans for the entire system employing different regulation techniques. Basic conditions of lake levels and outflows were adopted, against which lake levels and outflows derived from various regulation plans were compared. A dynamic programming technique is being used to maximize tangible benefits of regulating various combinations of Lakes. The maximization process assumes 100 percent forecast reliability of water supplies for the period of record 1900–1967.

As part of the overall studies of water-level fluctuation, work on related subjects simultaneously sought a better understanding of the hydrology of the Great Lakes Basin. The studies included forecasting of water supplies, ice retardation in connecting channels, rates of earth crustal movement, and the effect of tributary stream regulation on the Great Lakes water supply.

7.4.2 Shore Property

The shore property investigation determined how much lake level variations affect various shore property interests. It provided a means of evaluating the effects of reducing the past extremes of stage, using all related data available in both the United States and Canada. Specially organized task forces surveyed the total shoreline of the Great Lakes and their outflow rivers to Trois Rivières, Quebec, collecting extensive physical and economic data. Methods were developed for evaluating the effects of water level changes. Participating offices analyzed the assembled shore property inputs and applied them within the framework of the study to determine the effects of the regimen of lake levels and outflows produced by a preliminary regulation plan. Studies of expected future shoreline developments were made, including estimating future values and property use.

7.4.3 Navigation

The objective of the deep-draft navigation investigation was to develop a basis for measuring the effect of lake regulation on commercial shipping, by comparing the cost of Great Lakes water transportation under the existing regimen of levels with the cost under a regimen of further regulated lake levels. After a detailed analysis of past vessel movement patterns, studies have determined traffic volumes and future traffic patterns for principal commodity movements until the mid-project year 1995. Similarly, a study of the characteristics of representative lake and ocean vessels in the present fleet formed a basis from which to project a 1995 fleet. A methodology based on relative durations of lake stages was developed for determining and evaluating the effects of regulated lake levels on commercial navigation and applied to the developed plans.

The navigation study also investigated the effect of lake level regulation on recreational boating. Studies developed corresponding methodology and applied it to the anticipated future recreational boat fleet on the Great Lakes and St. Lawrence River.

Studies have made monthly estimates of United States and Canadian diversions required for navigation purposes in 1985 for each navigation canal in the Great Lakes-St. Lawrence system.

7.4.4 Power

The power investigation pertains to hydroelectric power generated from outflows of the Great Lakes. There are hydroelectric installations on the St. Marys River using Lake Superior outflows, on the Niagara River and Welland Canal using Lake Erie outflows, and on the St. Lawrence River using Lake Ontario outflows. The investigations determined the effect that regulating levels and outflows has on hydroelectric power and energy generation.

In general, the assessment of the effects of various regulation plans on power has been based on a comparison, for regulated and unregulated conditions, of the dependable capacity and energy output over a given period of record. The comparison power market conditions and system requirements expected to occur in the year 1985 were used. The power entities participating in the study had to synthesize a program for generation development additional to that now in existence from the present to the year 1985. To project beyond that time was not feasible in the study.

Investigators developed power supply conditions and projections of power requirements for 1985 so as to establish capacity and energy values for use in evaluating regulation plans.

7.4.5 Regulatory Works

The control of lake outflows in accordance with any regulation plan that may be developed in these studies would necessitate regulatory works in the outlet river of the Lake to be regulated. These works could include dredging to increase channel capacity and permit greater outflows at times of high lake supplies, and other compensatory works to maintain water-surface profiles satisfactory to navigation and riparian property interests. The estimated cost of such works will be based on design studies involving river hydraulics, site explorations and structural analyses. These studies began in November 1967.

Initially the feasibility and approximate cost of alternative means of regulating structures were considered for the St. Clair-Detroit

River and the Niagara River, the outlets of the two unregulated Lakes. Preliminary cost estimates for regulatory works for St. Clair-Detroit River and Niagara River were considered compatible with preliminary estimates of economic benefits, and detailed investigations were carried out. Additional work included studies of the possibility of increasing the flexibility in regulating Lakes Superior and Ontario, and the changes in outlet conditions necessary to provide this flexibility.

7.5 Implications of Benefits from Further Regulation of Great Lakes Levels and Flows

The International Joint Commission's Water Levels of the Great Lakes Study evaluated monetary benefits from further regulation of Great Lakes levels and flows to all recognized aspects of water resources management.

Approaches used to evaluate the effects of regulation plans on various interests are described in the following paragraphs. Methodologies used in this study are considered by experienced investigators to be the best that can be developed or adopted from other studies. Economic, hydrologic, and environmental assessments are being made of the effects of developed regulation plans on the various user interests.

7.5.1 Commercial Navigation Interests

The basis for determining benefits or losses to deep-draft navigation is the difference in the cost of transportation under existing water level variations and under a regulation plan which alters the frequency or the range of existing stages. Benefits or losses are determined as a dollar value related to changes in frequency of lake stages from the base condition. Ships that can take advantage of deeper water will load to the maximum available. Commercial navigation interests' objectives center on this single concept. Therefore, in the Great Lakes-St. Lawrence system there is the following general navigational objective: regulation should produce levels not lower than low water datum and average levels at least as high as the long-term average. Since some vessels are designed to take advantage of deeper water than is now available, it is in their interest to have as high a level as possible during the navigation season and have the flow in the connecting channels kept as uniform as possible. Further details on this evaluation are in Appendix C9, *Commercial Navigation.*

7.5.2 Hydro-Power Interest

Studies are determining potential benefits of further regulation of Great Lakes levels with regard to the overall cost of producing the power needed to service expected loads in the Michigan, New York, Ontario, and Quebec areas, as altered by the flows and levels which could result under the various regulation plans.

The methods used for computing and evaluating the effects of developed regulation plans provide load and power supply conditions estimated for 1985 on all existing Canadian and U.S. hydro installations, including the St. Marys Falls installation at the outlet of Lake Superior, the Niagara Falls plant, the St. Lawrence project at Barnhart Island, and Beauharnois and Cedar Rapids installations near Montreal. The existing hydro installations involved in this study have a total installed capacity of 8,070,700 kilowatts, with 4,909,100 kilowatts (61 percent) in Canada.

The power output from the flows and levels under a regulation plan is compared to the power output from the basis-of-comparison flows and levels. The effects of regulation plans on hydro-power installations are generally determined in two separate ways: the effect on dependable capacity and energy output; and the monetary evaluation of any changes in these two components as measured by effects on electric system costs. These studies are based on evaluation of differences obtained with the hydro projects operating in the power systems of New York, Michigan, Ontario, and Quebec with and without further regulation.

7.5.3 Shore Property Interests

Some other interests which are classified as shore property interests are primarily concerned with the relationship of the water levels and shoreline. Both low water levels and high water levels can damage these public, commercial, and private interests extensively.

7.5.3.1 Flood Control

Shore property damage from fluctuations in water levels includes both that associated with inundation or direct overland flooding and that of wind-generated waves, or a combination of these. The intensity of the shore damage varies with the elevation of the still-water level, augmented by the temporary increase in that level at a specific location generated by wind or barometric pressure gradient; the magnitude of wind-generated waves; and the extent of wave runup on the shore. The sum of the elevations of these four elements of a damaging event is called the ultimate storm water level.

Numerous other factors aggravate a damaging event, such as the nature of shore materials, exposure to onshore winds, offshore and onshore slopes, berms, and backshore elevations and widths, which affect the ability of the shore to absorb the energy created by the waves. The effects of these factors are continuous although often only specific damaging events are dramatized. An annual dollar damage value for erosion and inundation was determined for each Great Lakes shore reach on the basis of the frequency of the ultimate storm water level.

On some areas of shoreline, local protection works are not presently justified, but will be during the life of the project. Studies compute the effects of further regulation on future protection to be constructed as the difference in cost of economically justified protection works between regulated and base conditions expressed in annual charges for such works.

7.5.3.2 Recreation

Great Lakes beaches benefit from the addition and improvement of beach area caused by reduced high levels. Varying monetary values were assigned (average user-day value) to beaches of varying quality. A higher-rated beach would receive a higher user-day value than a lower-rated one. June through September was considered as the recreational season. Less than specified elevations on a Lake may produce adverse conditions, such as unwatering of materials such as mud or gravel undesirable for beach usage. Therefore, a designated elevation represents the lower limit on each Lake for optimum beach recreational value.

Evaluation of Great Lakes recreational boating involved boats based at marinas, boat clubs and harbors, at owners' properties, and trailer-borne boats. Assumptions and methodologies differ for the three segments since water level variations affect each of these differently and require a different basis for monetary evaluation.

Effects on boats based at marinas, boat clubs and harbors included the cost of dredging at low water periods, and property damage during low and high water periods. Studies assessed the effects on boats at individual properties and on trailer-borne boats on the basis of loss of boat use. The regulation objective for recreational boating assumes that regulation produces levels above a specified minimum stage for each Lake during the summer recreation season.

7.5.3.3 Fisheries and Wildlife

The existing fish and wildlife habitat along the Great Lakes shoreline represents an age-old ecological environment. This study is primarily concerned with the effect of altered water levels on shoreline marshes and estuaries, and their value to wildlife and aquatic fur-bearers. Shoreline wetlands are scarce when compared with the abundant upland habitat throughout the Great Lakes States.

Assessment of the effects on fisheries and wildlife required certain assumptions: that ecologic change as demonstrated throughout the period of record will recur during the project period; that marginal marshes of the Great Lakes have benefited biologically from period fluctuations of lake levels; and that while extreme high water levels may result in shoreline damage to controlled marshes, other types of uncontrolled shoreline habitat can benefit from protection by man-made structures.

Based upon estimated acres of shoreline habitat available, the average wetland acreage gained or lost by regulation provides an indication of the impact of regulation plans.

While studies to date indicate no measurable effect upon fish and their environment due to water level fluctuations, they have investigated biological assessment of possible effects, development of measurement procedures, and improved evaluation methods.

7.5.3.4 Water Intakes and Sewer Outfalls

Water and waste facilities have been designed to accommodate the average fluctuations of Great Lakes levels. However, when extreme levels occur, some municipalities and industries face significant problems.

This investigation dealt primarily with extreme low level conditions resulting in reduced intake capacity and increased power costs for water pumping facilities. The studies investigated problems of increased operations cost. While the quality of water being pumped is affected by extreme low levels, no significant monetary assessment could be found. An upper elevation limit for each Lake was fixed based upon a high level when sewer outfall operation problems may offset pumping benefits. Benefit to water intake facilities, in the form of reduced pumping costs, can be derived from higher lake levels. An average electrical power cost for pumping municipal and industrial Great Lakes water withdrawals was calculated utilizing a monthly comparison between the base condition and a regulation plan for each Lake.

7.6 Methods of Regulation Plan Design

Generally speaking, one can classify all regulation plans in one of two ways—plans which employ rigid rules in determining water releases from a lake and ignore possible future lake or water supply conditions, or plans which employ forecasts and consider the uncertain nature of a lake's water supply.

Regulation plans of the first type are more or less in operation on Lakes Superior and Ontario and were described in detail in Section 6. This type of rule may be modified to preclude tailoring the plans too closely to the historical water supply sequence. These modified or alternative approaches are:[10]

(1) the strict rule-and-limitation approach with rules and limitations developed over the historical supply, but tested over a long period of simulated water supplies

(2) the strict rule-and-limitation approach with outflow releases under extreme supply conditions at the same rate as that which would have occurred without regulation

Both approaches were developed in the same fashion. However, they do provide a good indication of probable future operation results. There would be few deviations from the plan as designed during actual operation. The alternative approaches do not provide optimum paper results over any given test period as does the strict rule-and-limitation type plan.

Regulation plans using the probabilistic approach are a natural evolution of the rule-and-limitation type plan. This employs a forecast of future supplies, appropriately considers water level conditions on other lakes of the system, and provides an indication of the probability of meeting the regulation criteria. Operating authorities determined the operational water release from Lake Ontario during the 1964 drought according to these criteria.

The probabilistic regulation plan also employs the historical supply period for development but does not separate critical supply sequences. It employs the entire supply period available for development. The principal features of this approach are:

(1) an indicator of current supply conditions within the system

(2) supply probability curves (developed from the historical water supply record) or a method of forecasting future supplies

(3) outflow determination methods or operational rules for determining water releases

(4) maximum, minimum, or target elevation for a subsequent period or for a particular month (these levels may be exceeded)

(5) maximum and minimum outflow limitations related to some derived or preregulation condition

(6) a procedure for utilizing accumulated storage on the lake, within the system, or the balancing of storage between lakes

In a regulation plan of this type, these features fit into an operational procedure, and the regulated release for the coming regulation period is obtained in three steps:

(1) Water supplies and lake levels for a given period are forecast.

(2) The resulting levels are compared with the objectives and criteria for regulation on a given lake or for the system.

(3) Adjustments are made to the outflow (employed in step 1 to determine the future levels) by using the accumulated storage within the system or by balancing storage within the system so as to best meet the objectives and criteria for regulation.

Development of the probabilistic plan is accomplished by testing tentative rules over a supply period. In this case the entire period is used rather than selected critical sequences. After the initial test, the tentative rules are modified to refine techniques and improve the results in light of the objectives.

Comparison of the two methods over a given supply period indicates that the strict rule-and-limitation type plan provides the best numerical results.

However, employing the two types of rules over various periods of simulated supplies shows that the stochastic approach provides a more realistic forecast of regulation results. This is because the second approach considers the fact that the sequence and magnitude of future supplies may be materially different than that of the past. This plan also permits a continual evaluation of the probable effect on the lake level and the likelihood of meeting the objective or of violating the fixed criteria of a specific regulation plan.

The use of simulated water supply data provides a valuable tool in evaluating a regulation plan. The study by the International Great Lakes Levels Board of the International Joint Commission has applied simulated water supply data. It is generally considered that any operational plan of either of the above two types should be evaluated in the course of development over a long-term simulated supply record, as well as over the comparatively short-term historical record. Such an evaluation would better indicate the results of regulating a given Lake or the entire system.

7.7 Summary of Levels Board's Final Report

The International Great Lakes Levels Board, in its report entitled, "Regulation of Great Lakes Water Levels," dated December 7, 1973, listed 12 findings and five conclusions as the result of its studies. This report was released to the public by the IJC on February 26, 1974. There are seven technical appendixes to this report which are expected to be available by June 1974. The IJC has approved plans to hold public hearings on the Board's report in late summer 1974. The findings progress from some general concepts regarding Great Lakes hydrology and hydraulics to more specific assessments of various measures for further regulating the Great Lakes. The conclusions address the feasibility of the major alternatives for alleviating the problem of extreme levels and flows.

7.7.1 Findings

7.7.1.1 Water-Level Fluctuations

As its first finding the Board pointed out that there are three categories of water-level fluctuations on the Great Lakes: long-term, seasonal, and short-period. The long-term range of levels varies from 3.8 feet on Lake Superior to 6.6 feet on Lakes Michigan-Huron and Lake Ontario. A century of record on the Great Lakes does not reveal any regular, predictable cycle such as one might expect. The interval between high and low levels varies widely and erratically.

Seasonal fluctuations result from the annual hydrologic cycle. The winter snow and the spring melt cause higher supplies in the spring and early summer than during the rest of the year. Seasonal fluctuations average 1.1 feet on Lake Superior and Lakes Michigan-Huron, 1.5 feet on Lake Erie, and 1.9 feet on Lake Ontario.

Short-period fluctuations are caused by meteorological disturbances and may last from a few hours to several days. Wind and differences in barometric pressure cause the lake surface to tilt. Although the lake surface elevation at a particular location has changed as much as eight feet from such causes, there was no change in the volume of water in the Lake. Short-period fluctuations are superimposed on the level resulting from long-term and seasonal fluctuations. Superimposed on all three types of fluctuations are wind-induced waves.

From its study of systems hydrology and hydraulics the Board found that the large storage capacities and restricted outflow characteristics of the Great Lakes are highly effective in providing a naturally regulated system. The net supply to the Lakes from precipitation and evaporation may vary widely. However, large variations in supply are absorbed and modulated. Consequently, lake outflows vary by much smaller amounts than the flows of other large river systems, such as the Columbia, Missouri, Ohio and Mississippi.

7.7.1.2 Mean Levels and Outflows

Mean levels and outflows of all the Lakes will change progressively with time as a result of the steadily increasing consumptive use of water in the Basin and the nearly imperceptible movement of the earth's crust in the region of the Great Lakes Basin.

The increasing consumptive use of water will gradually decrease the net supply to the Lakes. Based on projected increases in population, land use, industry, and power generation, consumptive use could increase from a Basin total of 2,300 cfs in 1965 to 6,000 cfs in 2000 and 13,000 cfs by the year 2020. If the present growth trend in consumptive use continues, this problem will require careful and serious study.

The tilting of the earth's crust in the region is gradually raising the northeastern limits of the Basin relative to its southwestern limits. For example, the differential movement between the northeast and southwest shores of Lakes Michigan-Huron is about one foot per century. This relative movement is probably the rebounding of the earth's crust from the weight of ice-age glaciers. The net effect of the tilting is to increase gradually the mean water elevation of the unregulated Lakes. For regulated Lakes, the effect can be counteracted by adjustment of the regulation regime.

7.7.1.3 Further Lake Regulation

A major finding of the Board concerned the potential benefits of further lake regulation. To the extent that the Lakes already possess a high degree of natural regulation and are artificially regulated by works at the outlets of Lake Superior and Lake Ontario, only small improvements are practicable without costly additional regulatory works and remedial measures.

A very limited reduction in the range of stage of a lake could be obtained by a redistribution of its outflows during the year. Further compression of the range could only be achieved by increasing the flows of its outlet river. This in turn would increase the range of levels and outflows of the downstream Lakes. By regulating the downstream Lakes, adverse hydrologic and economic effects could be minimized. But the result would be to transfer these variations to the St. Lawrence River, where significant physical constraints exist. Consequently, only minor reductions in the range of stage would be possible without costly remedial measures to avoid adverse effects downstream.

The Board's final report incorporates the full examination of Lake Superior regulation that was presented in the Interim Report to the IJC dated March 15, 1973. The Board reaffirmed its earlier finding that a new regulation plan for Lake Superior, Plan SO–901, can be expected to yield small long-term average annual net benefits to the system at a minimal cost.

The rules for Plan SO–901 are based upon the levels of both Lake Superior and Lakes Michigan-Huron. They involve routine changes in the gate settings during winter as well as during the open-water season. Field tests during the study showed year-round operation to be feasible. The annual cost of Plan SO–901 would be $70,000, including amortization charges and surveillance of river ice conditions.

Under instructions from the IJC, the International Lake Superior Board of Control has been using Plan SO–901 as a guide for the emergency regulation of Lake Superior during the year starting July 1, 1973.

The Board found that two preliminary plans for the combined regulation of Lakes Superior, Erie, and Ontario exhibited favorable benefit-cost ratios. It tried three approaches, all using the existing regulatory works for Lakes Superior and Ontario and preserving the existing criteria and other requirements of the IJC Orders of Approval for the regulation of Lake Ontario.

The first approach considered regulation of Lake Erie with channel enlargement and a control structure in the upper Niagara River. The $108-million cost of construction for this alternative resulted in a benefit-cost ratio of less than one.

The second approach was channel enlargement in the upper Niagara River and regulation of Lakes Superior and Ontario in accordance with Plan SO–901. In this approach only Lakes Superior and Ontario would be directly controlled. Lake Erie levels would fluctuate naturally in a lower range. This plan, numbered SEO–901, has a very favorable benefit-cost ratio. However, since it would permanently lower the level of Lake Erie, it would cause irreversible environmental harm.

In the third approach the outflow from Lake Erie would be increased during periods of above-average supply. This would be done by building a diversion channel through Squaw Island from the Black Rock Canal to the Niagara River at an estimated cost of five million dollars. This plan, numbered SEO–42P, would increase Niagara River discharge by 8,000 cubic feet per second during periods of above-average water supply. The regulation plan for Lake Ontario would be modified to avoid detriments to that Lake and downstream interests. The benefit-cost ratio for Plan SEO–42P would be 17.

In the development of these Lake Erie plans, benefits tended to be limited by the amount of water which would be discharged into Lake Ontario and down the St. Lawrence River within present constraints. Thus, the ultimate refinement of any Lake Erie plan depends on the results of further studies of the regulation of Lake Ontario. Such studies should consider all the benefits on all the Lakes which could be obtained through regulation of Lake Erie and changes in the regulation of Lake Ontario.

The Board found that regulation of Lakes Michigan-Huron by construction of control works and dredging of channels at their outlet, combined with regulation of Lakes Superior and Ontario, would not provide benefits commensurate with costs.

Several alternative plans were developed, and a trial plan was evaluated in detail. This representative plan would require regulatory works in the St. Clair and Detroit Rivers at a cost of $150 million and Detroit River channel enlargement at a cost of approximately $50 million. The equivalent annual cost, including the additional costs for Lake Superior, would be $18 million. The estimated upper limit of annual benefits from this plan is only $3 million.

To insure a comprehensive consideration of all alternatives, the Board studied plans for the combined regulation of all five Lakes. It found that regulation of all five Lakes, employing existing control works for Lakes Superior and Ontario and newly constructed works for Lakes Michigan-Huron and Erie, would not provide benefits commensurate with costs.

Several alternative plans were developed and a trial plan was evaluated in detail. This representative plan would require regulatory works in the St. Clair, Detroit, and Niagara Rivers at a cost of $266 million, and Detroit and Niagara River channel enlargements at a cost of $105 million. The equivalent annual cost, including the additional cost of Lake Superior, would be $28 million. The estimated upper limit of annual benefits from this plan is only $15 million.

The Board found that the physical dimensions of the St. Lawrence River are not adequate to accommodate the record supplies to Lake Ontario received in 1972–73 and at the same time satisfy all the criteria and requirements of the IJC Orders of Approval for the regulation of Lake Ontario. When the Board addressed alternatives for Lake Ontario based upon the supplies received over the study period 1900–1967, it found that Plan 1958–D satisfied the criteria and other requirements of the IJC Orders of Approval with only a few exceptions. The Board was then prepared to conclude that structural alternatives for Lake Ontario did not merit further consideration. However, even with the recent extraordinary discretionary deviations from Plan 1958–D, it was not possible to accommodate the record high supplies of 1972–73 and meet all the regulation criteria and other requirements of the IJC Orders of Approval for Lake Ontario regulation. Recent studies of the International St. Lawrence River Board of Control have confirmed this finding.

Another finding of the Board was that works in the St. Clair and Detroit Rivers to compensate hydraulically for the remaining effect of the 25- and 27-foot navigation projects would increase shoreline damage from higher lake levels. The navigation projects in the St. Clair-Detroit River system were authorized with provision for compensatory works to prevent the ultimate lowering of Lakes Michigan-Huron from the increased channel capacity of the rivers. During construction some excavated material was placed so that it would retard the river flow. However, full compensation has not been achieved. The higher outflows have lowered the level of Lakes Michigan-Huron by 0.59 foot. This provides an average annual benefit to shore property of $12 million, compared to an average annual loss of $1.3 million to navigation.

7.7.1.4 Hydrologic Forecasting

An important subject affecting Great Lakes regulation is hydrologic forecasting. The Board found that better and faster determination of Basin hydrologic response will allow improvement in regulation. Studies indicate that accurate forecasts of water supplies four months in the future could increase the benefits of regulation by as much as one-third. However, there is very little promise for forecasting precipitation more than a few weeks in advance. Improvement is possible in the forecast of runoff into the Lakes from precipitation which has already fallen on tributary land areas. Such forecasts, based upon data from a remote-access, hydrometeorological network, should allow partial prediction of supplies and hence improved regulation.

7.7.1.5 Minimizing Shore Property Damage

Finally, the Board found that the most promising measures for minimizing future damage to shore property are strict land-use zoning and structural setback requirements. The shoreline surveys and damage evaluations for this study indicated that a significant portion of the shore property damage is due to flooding and wave attack on existing shore structures. The surveys also indicated that shoreline development is proceeding at an accelerating rate. In the future, damages will continue in developed areas where existing structures are too close to the Lake. Loss of unprotected shoreline through erosion will also continue. However, future damage can be reduced by land-use zoning to limit development and to require setback of structures from the Lake, where development is permitted. If such measures are not taken, future development will continue to follow the general trend, and total shoreline damage will continue to increase.

7.7.2 Conclusions

Considering its entire study and in particular its 12 findings, the Board reached five conclusions:

(1) Small net benefits to the Great Lakes system would be achieved by a new regulation plan for Lake Superior which takes into consideration the levels of Lake Superior and of Lakes Michigan-Huron. The new plan would employ the existing control works for Lake Superior and Lake Ontario, incorporate the existing plan for the regulation of Lake Ontario, and satisfy the existing criteria and requirements for Lake Ontario regulation to the same extent as Plan 1958–D. The shore property interests on Lakes Michigan, Huron, and Erie would be the main beneficiaries. Navigation and power interests would also benefit. Shore property interests on Lake Superior would incur a net loss. There would be no significant adverse environmental effects.

(2) Regulation of Lakes Michigan-Huron by the construction of works in the St. Clair and Detroit Rivers does not warrant further consideration. To regulate the outflow of Lakes Michigan-Huron and at the same time maintain something similar to the natural profile of the 89-mile St. Clair-Detroit River system would require at least nine control structures. The cost of constructing this many works far exceeds any benefits to be expected from regulating Lakes Michigan-Huron outflows.

(3) Further study is needed of the alternatives for regulating Lake Erie and improving the regulation of Lake Ontario, taking into account the full range of supplies received to date. The conditions that showed the need for such further study came about at the scheduled end of the Board's studies. They are still continuing. Therefore, the Board was not able to make a comprehensive study of all these aspects and include definitive findings and conclusions in its report. Further study should examine all constraints on regulation of these Lakes downstream to Trois Rivières on the St. Lawrence River and alternative means by which such constraints may be met or modified; benefits and costs of the alternatives; and other factors which could affect the acceptability of the alternatives, including their environmental effects.

(4) The hydrologic monitoring network of the Great Lakes Basin should be progressively improved. The responsible national agencies of Canada and the United States should cooperate in studying the benefits and costs of specific alternatives for expanding hydrologic monitoring, then adopt a step-by-step expansion program incorporating those measures which are feasible and desirable.

(5) Appropriate authorities should act to institute land-use zoning and structural setback requirements to reduce future shoreline damage. There should be a concerted program of zoning and setback requirements based upon the realities of natural lakeshore processes. The Great Lakes are a dynamic natural system. Their water levels will fluctuate even with regulation. In periods of high water, storm-driven waves will flood and erode vulnerable shorelands. To live in harmony with his environment and avoid continual losses, man must keep development out of the danger zone.

Section 8

DEVELOPMENT OF DETAILED LAKE LEVEL EFFECTS

8.1 Introduction

The term ultimate water level is used to designate the extreme water-level elevation at a reach of the Great Lakes shoreline due to a storm on the lake. Strong winds tilt the water surface of the lake in the direction of the wind, lowering the water level along the upwind shore and raising the levels at the downwind shore. The maximum elevation of the water surface along the shore is termed the storm water level. The large waves generated during the storm break as they arrive at the shore and run up the beach. The maximum vertical distance above storm water level that the breaking wave reaches is called the wave run-up. Thus the ultimate water level at a reach for a storm is the elevation of the storm water level plus the wave run-up. The effects of wind and waves on the lake levels are diagrammed in Figure 11–33.

Studies computed ultimate water levels on IGLD (1955) to evaluate regulation plans for the December 1965 survey report of U.S. Army Corps of Engineers, North Central Division, Appendix C.[45] Similar data were developed for the IJC's Great Lakes Water Levels Study. The 36 reaches of the Great Lakes shores for which studies computed ultimate water levels are shown in Figures 11–34 through 11–38. Assigned numbers identify the reaches. The ultimate water levels calculated for these reaches for the period of data available are tabulated at the end of this appendix. The ultimate water level for a reach allows only for average reach conditions. Actual local levels may vary.

Ultimate levels should be used carefully for purposes other than comparing effects of regulation or general planning uses. The 15 water level gaging stations and 16 weather stations used to determine storm water levels and corresponding wind speeds and directions are also identified in Figures 11–34 through 11–38. The water level and weather stations used for each reach are listed in Table 11–34.

The storm water levels used for each reach are the maximum instantaneous elevations recorded each month at the water level station as adjusted to constant diversion and outlet conditions or basis-of-comparison conditions. The conditions used to obtain basis-of-comparison[36] stages and flows are constant diversions of 5,000 cfs into Lake Superior, 3,200 cfs out of Lake Michigan, and 7,000 cfs through Welland Canal from Lake Erie into Lake Ontario. Fixed outlet regimens are Lake Superior regulated under the September 1955 modified Rule of 1949, 1933 outlet conditions for Lake Huron, 1953 outlet conditions for Lake Erie, and Lake Ontario regulated under Plan 1958–D. Section 6 has detailed descriptions of these conditions.

The adjustment to be applied to the recorded instantaneous maximum levels is the same for a given month for all stations on a lake and is the difference between the basis-of-comparison stage and the monthly mean recorded levels at the following stations: Marquette, Michigan on Lake Superior; Harbor Beach, Michigan on Lakes Michigan-Huron; Cleveland, Ohio on Lake Erie; and Oswego, New York on Lake Ontario.

8.2 Wave Run-Ups

Investigators have computed wave run-up used in this determination of ultimate water levels from the equation for a smooth and impermeable structure given in Appendix C of the December 1965 Army Engineer Report.[45] Since the ultimate water levels were of a comparative nature, no reductions in the computed run-ups were considered necessary to account for the roughness and permeability of the beaches and structures in the different reaches. The equation from Appendix C was rewritten in the form:

$$R = 2.3 m T H^{0.5} \qquad (9)$$

where R is the wave run-up; m is the representative slope of the beach or protective structure; T is the wave period; and H is the wave height.

(Continued on page 94)

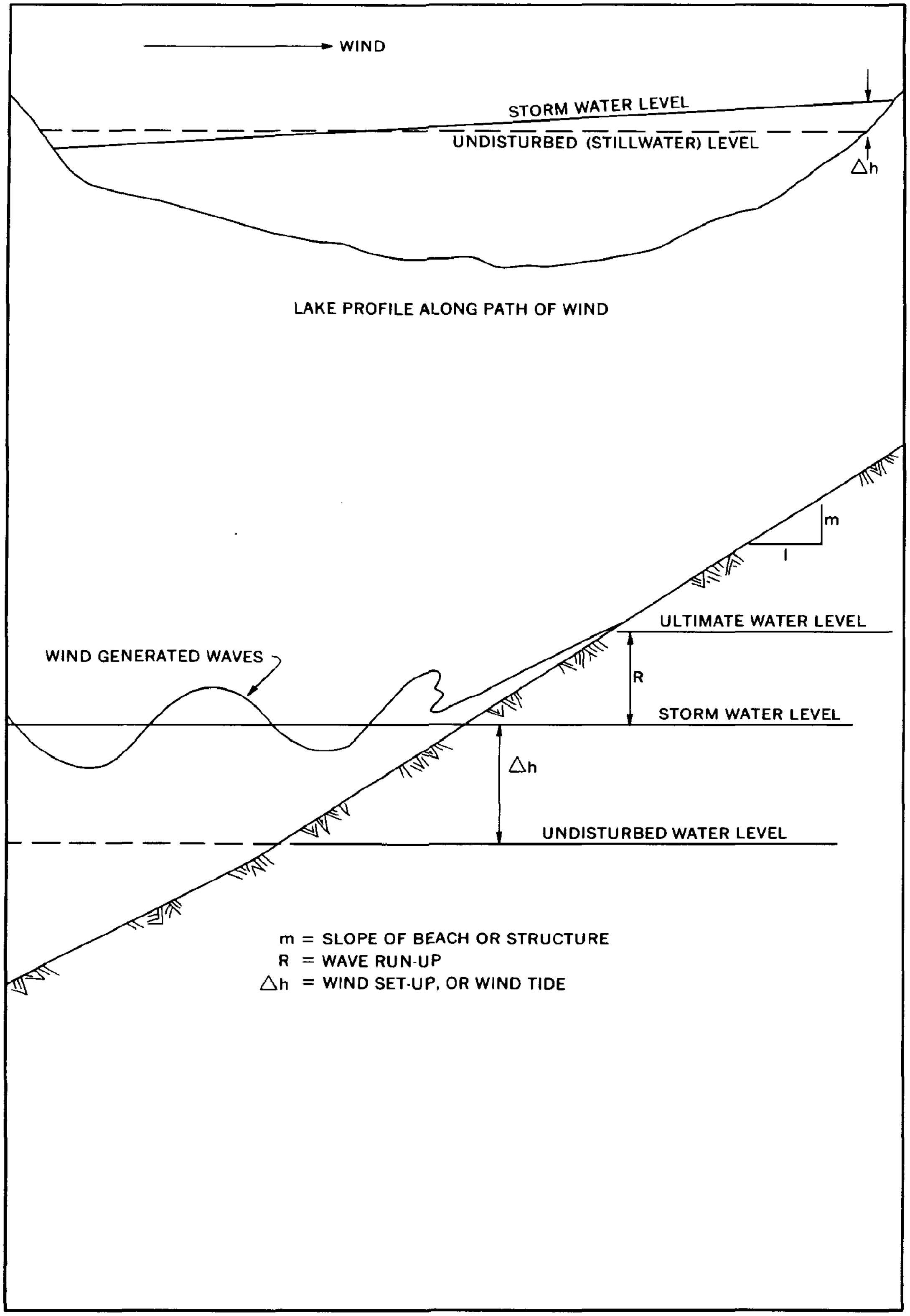


FIGURE 11–33 Diagram of Storm Effects on Water Levels

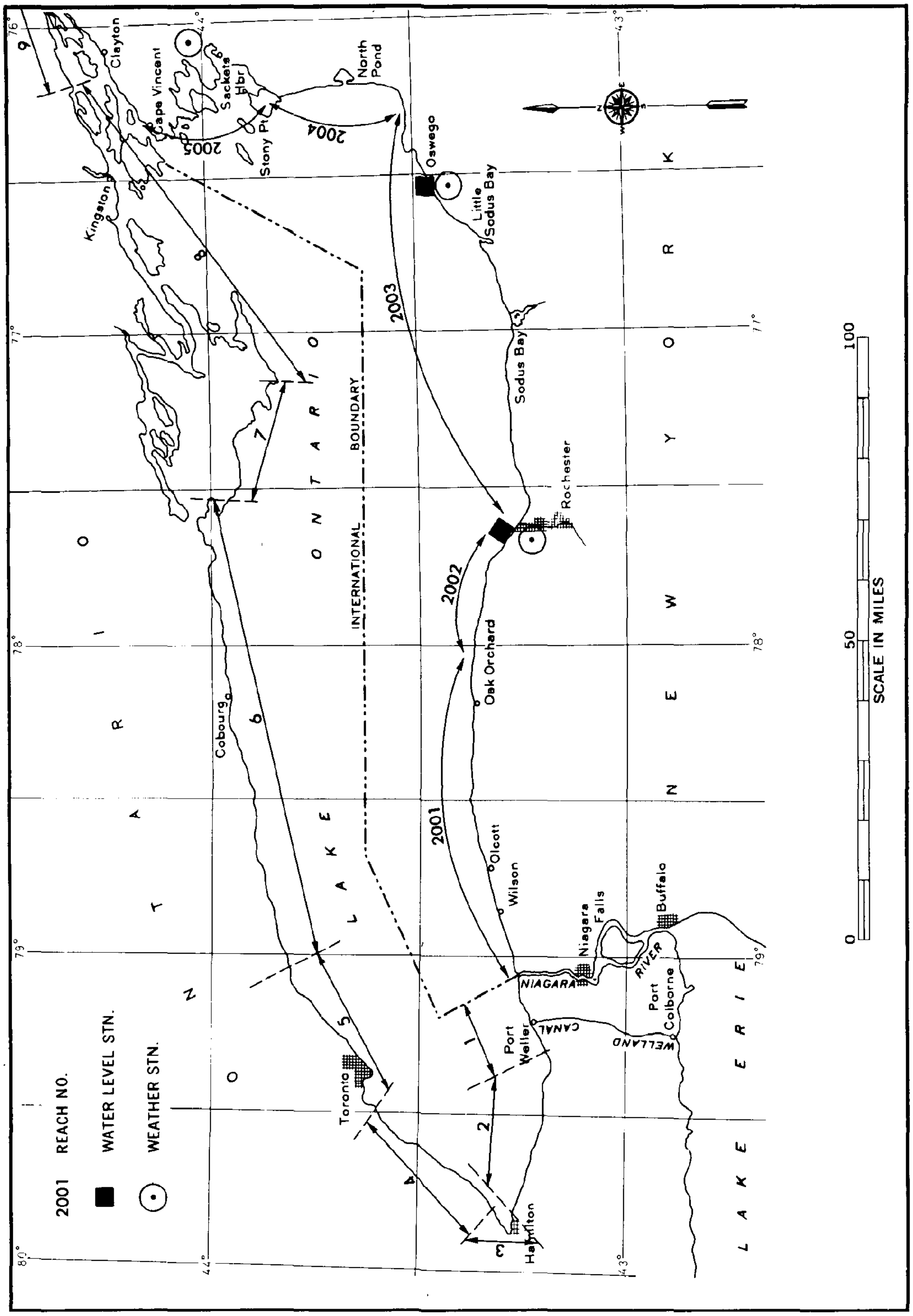


FIGURE 11–34 Lake Ontario Location Map

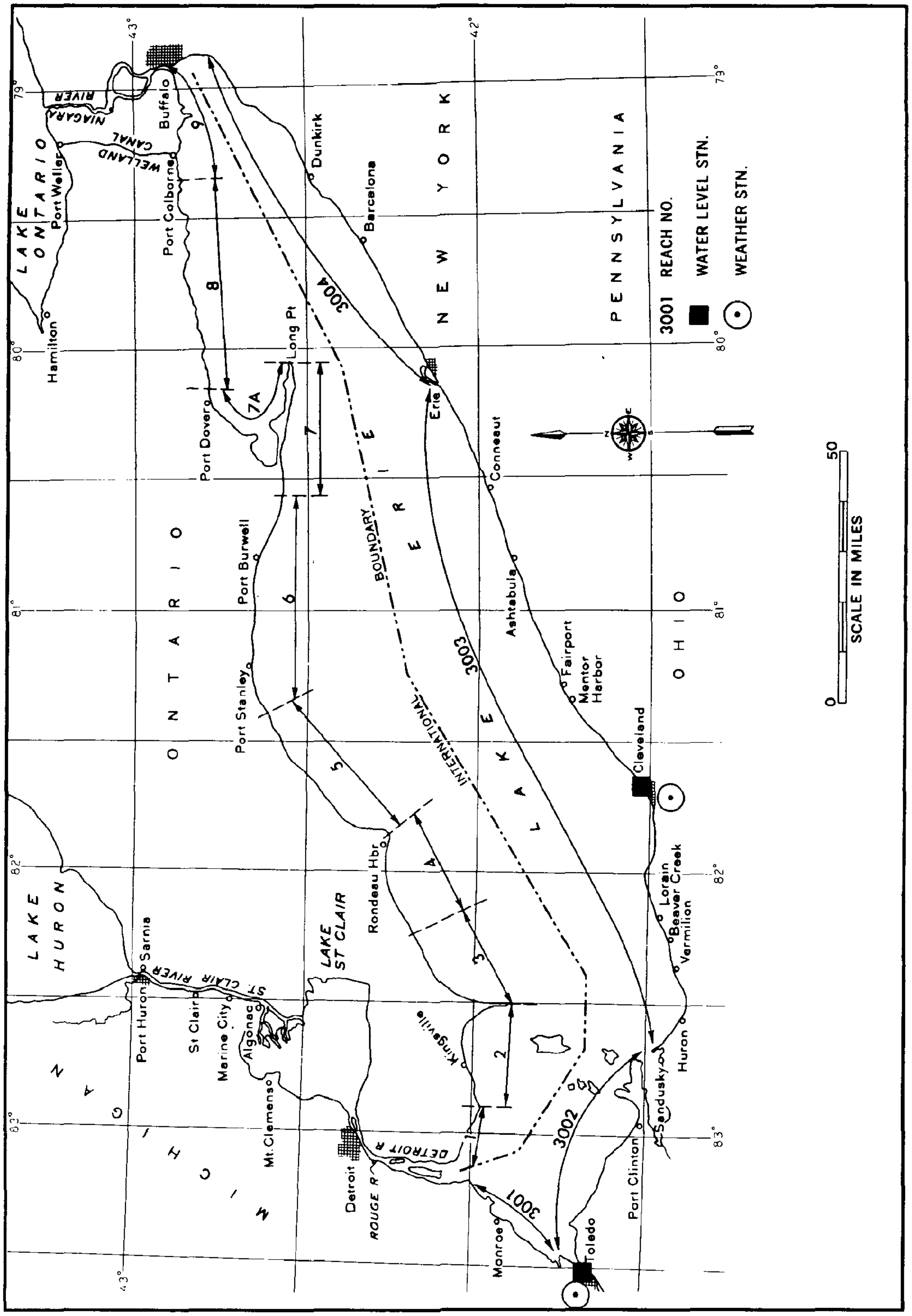


FIGURE 11-35 Lake Erie Location Map

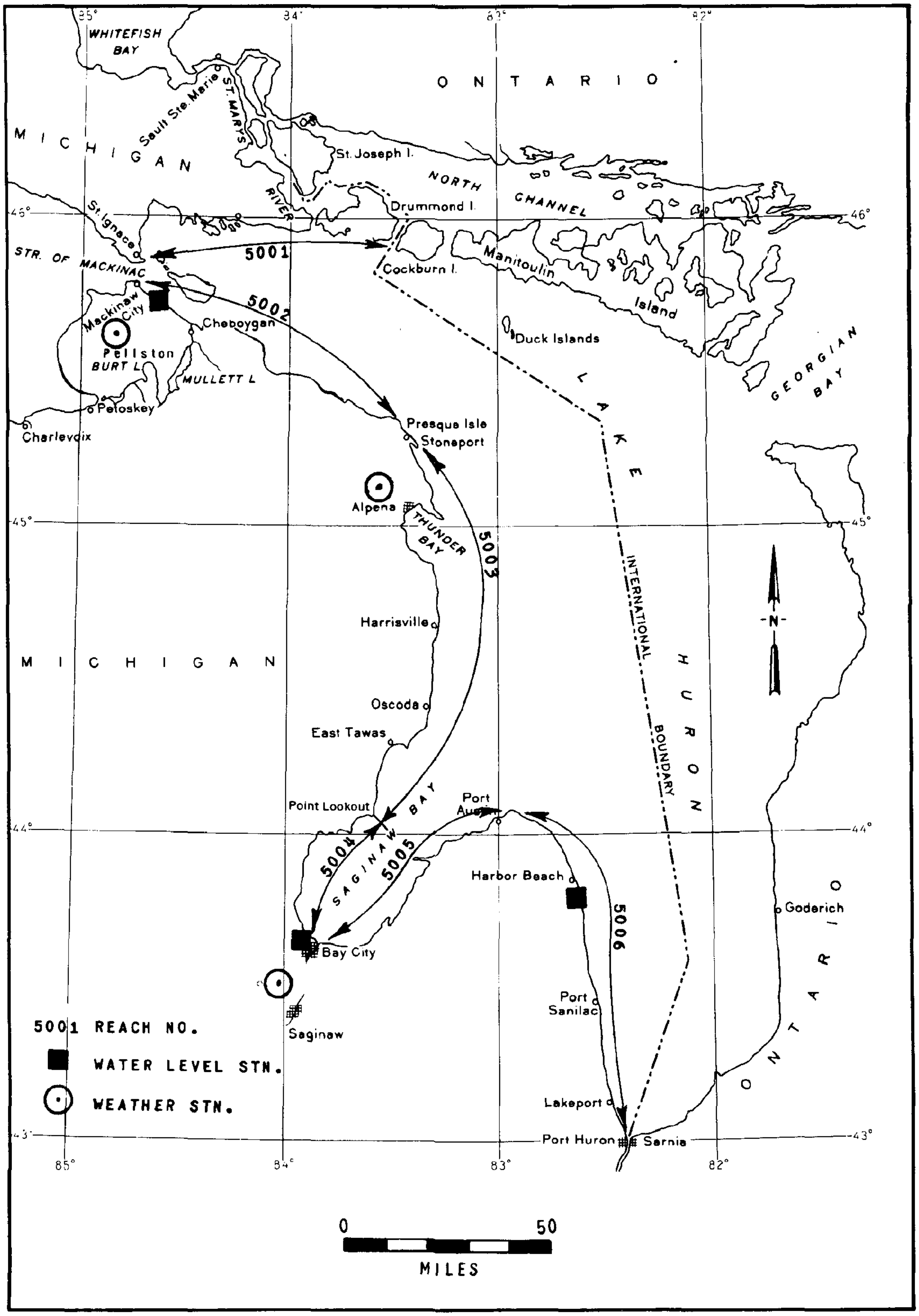


FIGURE 11–36 Lake Huron Location Map

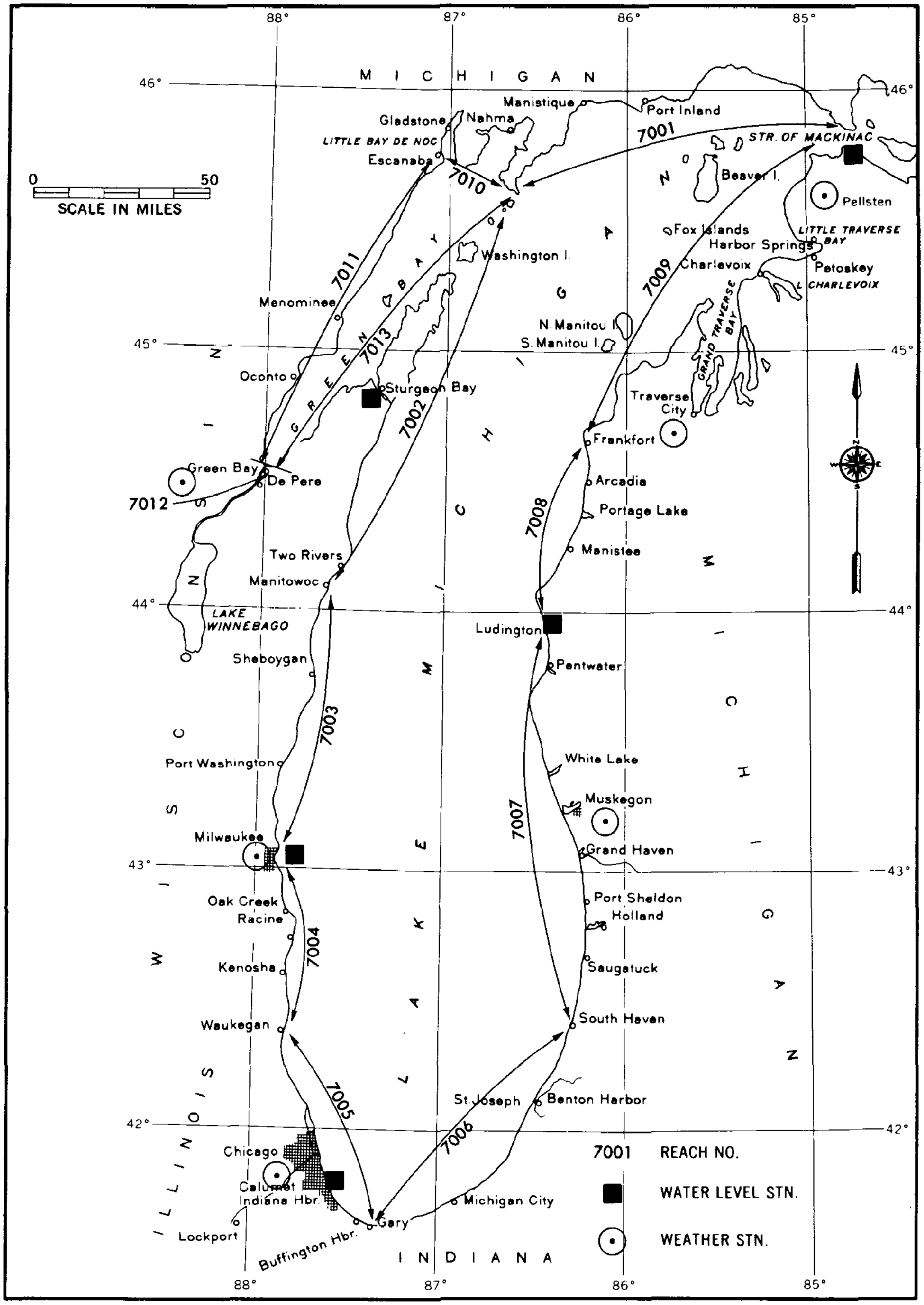


FIGURE 11–37 Lake Michigan Location Map

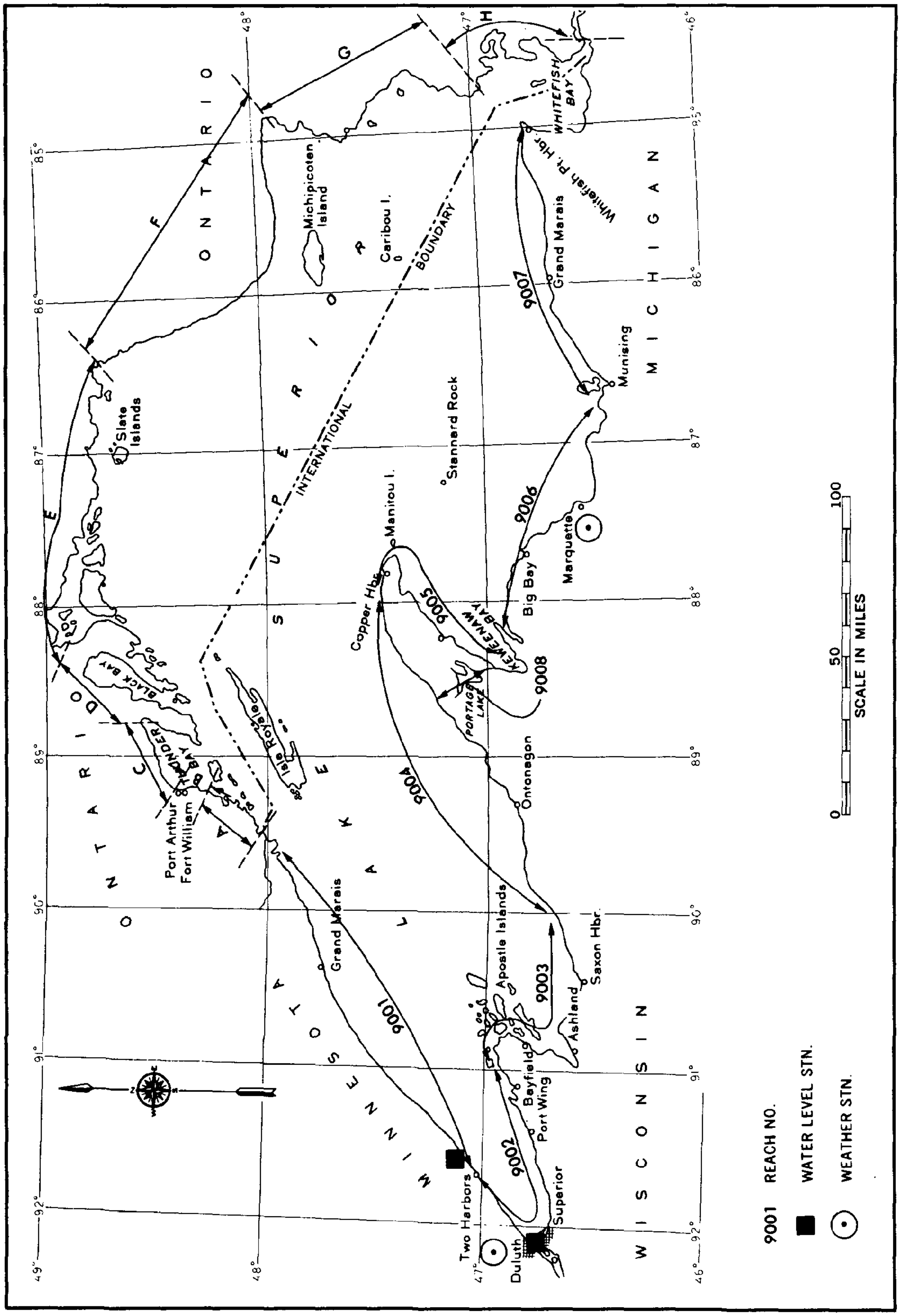


FIGURE 11–38 Lake Superior Location Map

TABLE 11-34 Ultimate Water Level Reaches—Selected Wind and Water Level Stations

Reach Number	Reach of Shore	Weather Station	Water Level Gage	Period of Record
2001	Niagara River to Hamlin Beach	Rochester	Rochester	1953-1964
2002	Hamlin Beach to Rochester	Rochester	Rochester	1953-1964
2003	Rochester to Port Ontario	Oswego	Oswego	1933-1953
2004	Port Ontario to Stony Creek	Oswego	Oswego	1933-1953
2005	Stony Creek to Tibbetts Point	Watertown	Oswego	1946-1964
3001	Pointe Mouillee to Toledo	Toledo	Toledo	1905-1964[1]
3002	Toledo to Sandusky	Toledo	Toledo	1905-1964[1]
3003	Sandusky to Erie	Cleveland	Cleveland	1904-1964
3004	Erie to 11 mi. south of Buffalo	Buffalo	Erie	1900-1964
5001	International Boundary to Straits of Mackinac	Pellston	Mackinaw City	1941-1964
5002	Straits of Mackinac to Presque Isle	Pellston	Mackinaw City	1941-1964
5003	Presque Isle to Point Lookout	Alpena	Harbor Beach	1904-1961
5004	Point Lookout to Essexville	Saginaw	Essexville	1953-1964
5005	Essexville to Pointe Aux Barques	Saginaw	Essexville	1953-1964
5006	Pointe Aux Barques to Port Huron	Saginaw	Harbor Beach	1913-1964[2]
7001	Straits of Mackinac to Point Detour	Pellston	Mackinaw City	1941-1964
7002	Point Detour to Manitowoc	Green Bay	Sturgeon Bay Canal	1950-1964
7003	Manitowoc to Milwaukee	Milwaukee	Milwaukee	1905-1964
7004	Milwaukee to Waukegan	Milwaukee	Milwaukee	1905-1964
7005	Waukegan to Gary Harbor	Chicago Midway	Calumet Harbor	1928-1968
7006	Gary Harbor to South Haven	Chicago Midway	Calumet Harbor	1928-1964
7007	South Haven to Big Sable Point	Muskegon	Ludington	1950-1964
7008	Big Sable Point to Empire	Traverse City	Ludington	1950-1964
7009	Empire to Straits of Mackinac	Pellston	Mackinaw City	1941-1964
7010	Point Detour to Escanaba	Green Bay	Sturgeon Bay Canal	1950-1964
7011	Escanaba to Green Bay	Green Bay	Sturgeon Bay Canal	1950-1964
7012	Green Bay, Wisconsin	Green Bay	Sturgeon Bay Canal	1950-1964
7013	Green Bay to Point Detour	Green Bay	Sturgeon Bay Canal	1950-1964
9001	International Boundary to Two Harbors	Duluth	Two Harbors	1950-1964
9002	Two Harbors to Point Detour	Duluth	Duluth	1951-1964
9003	Point Detour to Oronto Bay	Marquette	Marquette	1905-1964
9004	Oronto Bay to Copper Harbor	Marquette	Marquette	1905-1964
9005	Copper Harbor to Huron Bay	Marquette	Marquette	1905-1964
9006	Huron Bay to Au Train Bay	Marquette	Marquette	1905-1964
9007	Au Train Bay to Whitefish Point	Marquette	Marquette	1905-1964
9008	Keweenaw Waterway	NONE	Marquette	1905-1964

[1] 27 years missing data

[2] 10 years missing data

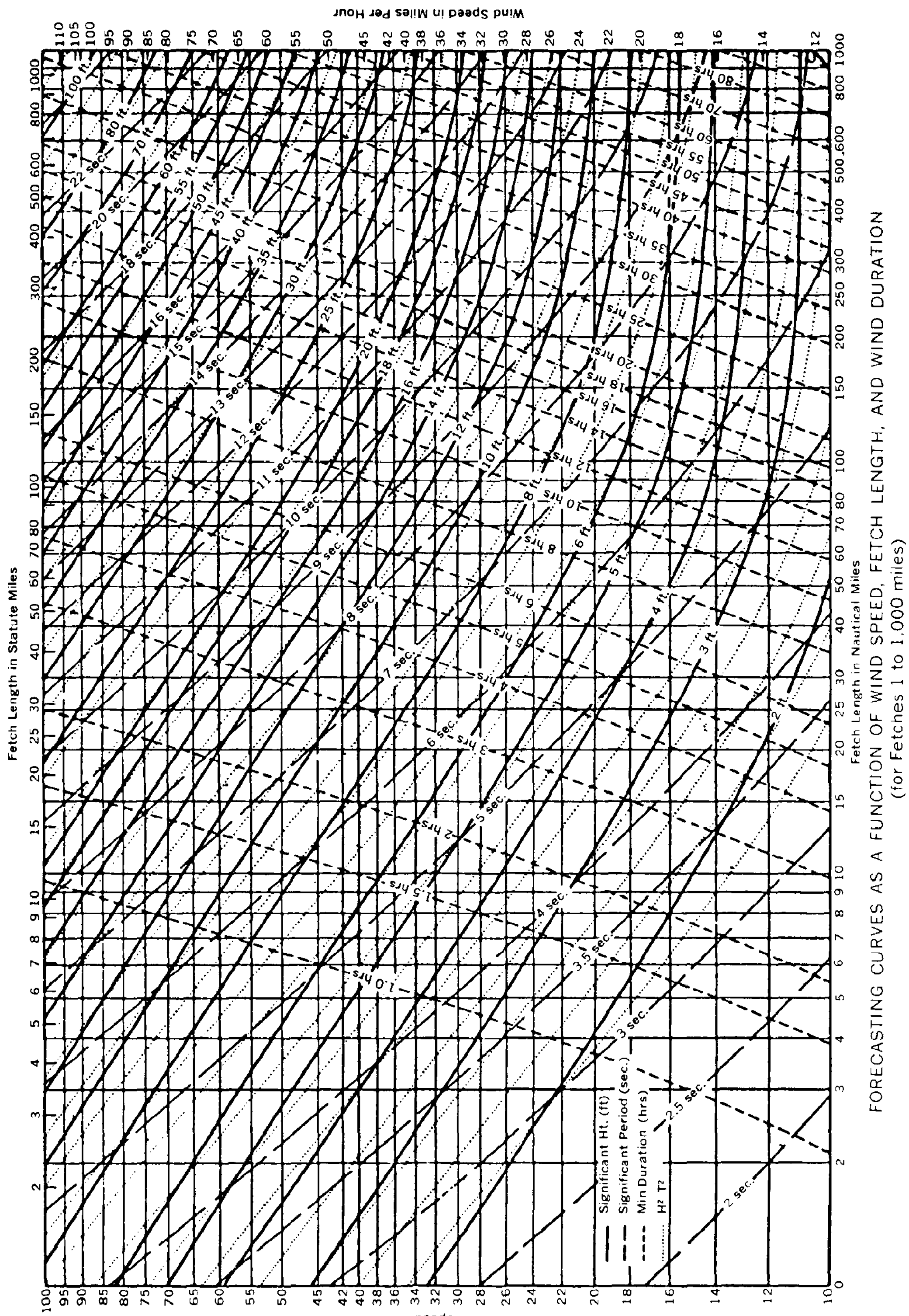


FIGURE 11–39 Deep Water Wave Curves

Investigators have derived wave periods and heights for Equation 9 from hourly wind data and the equivalent fetch lengths as shown in Tables 11–35 and 11–36 by utilizing the significant deepwater wave curves shown in Figure 11–39. They took these curves from Technical Report No. 4, U.S. Army Coastal Engineering Research Center,[39] and computed average wind speed and direction from hourly wind data at each weather station for periods of one to two hours before the time each maximum storm water level was recorded. Wind speeds recorded were increased at the land stations by a factor of 1.2 to account for the reduced speed of the wind as it leaves the lake and blows over the land. By trial, adjusted average wind speeds were used to determine the maximum wave height and the corresponding wave period from the curves in Figure 11–39.

The maximum height of a wave that can be sustained at the depth at which the deepwater wave breaks is given by the equation shown in Appendix C of the 1965 survey report[45] as follows:

$$\text{Max. } H = \frac{B.D.}{1.28} \tag{10}$$

where $B.D.$ is the breaking depth or the difference between the storm water level and the appropriate lake elevation on IGLD (1955): Lake Superior, 599.3 feet; Lake Michigan, 576.5 feet; Lake Huron, 576.5 feet; Lake Erie, 568.6 feet; Lake Ontario, 242.6 feet. The lesser of the two wave heights determined from curves in Figure 11–39, Equation 10, and the period from the curves were used to obtain the wave run-up in Equation 9.

The ultimate water levels for reach computed from basis-of-comparison storm water levels for undiked or natural shore conditions are shown at the end of this appendix. Field observations of waves and wave run-up during storms on the Great Lakes are needed to improve the method of determining ultimate water levels.

TABLE 11–35 Undiked and Diked Representative Slopes

Reach No.	Representative Slope Undiked	Representative Slope Diked
2001	0.100	0.200
2002	0.050	0.200
2003	0.125	0.200
2004	0.058	0.200
2005	0.111	0.200
3001	0.083	0.200
3002	0.071	0.200
3003	0.125	0.300
5001	0.062	0.200
5002	0.045	0.200
5003	0.020	0.200
5004	0.026	0.200
5005	0.042	0.200
5006	0.167	0.200
7001	0.100	0.200
7002	0.091	0.200
7003	0.100	0.200
7004	0.083	0.200
7005	0.058	0.200
7006	0.143	0.200
7007	0.200	0.200
7008	0.333	0.333
7009	0.200	0.200
7010	0.067	0.200
7011	0.100	0.200
7012	0.111	0.200
7013	0.125	0.200
9001	0.250	0.250
9002	0.333	0.333
9003	0.33	0.333
9004	0.062	0.333
9005	0.143	0.333
9006	0.091	0.333
9007	0.167	0.333

8.3 Other Information

In addition to the sudden rises of water level producing the storm water levels described above, short-period rises called surges, caused by intense squall lines moving across the Lakes, occur occasionally on all the Great Lakes. The southern basin of Lake Michigan has had numerous surges. One in June 1954 caused a 10-foot rise and killed seven people fishing off a pier on the Chicago waterfront. The amplitude of a short-period fluctuation depends on the configuration of the beach and shoreline, and varies from place to place. One may obtain the approximate amplitude of short-period rises and falls at a water level

TABLE 11–36 Equivalent Fetches in Miles

Reach No.	Wind Directions N	NE	E	SE	S	SW	W	NW
2001	38	53	42	0	0	0	26	38
2002	44	50	42	0	0	0	23	49
2003	36	23	9	0	0	42	66	62
2004	14	0	0	0	11	44	59	36
2005	0	0	0	18	37	47	26	6
3001	0	0	35	30	20	0	0	0
3002	30	30	20	0	0	0	0	15
3003	50	100	0	0	0	0	60	55
5001	0	0	52	80	51	25	21	0
5002	31	42	59	50	0	0	17	25
5003	61	77	82	73	40	10	0	12
5004	29	69	52	13	19	20	10	0
5005	63	80	46	0	0	16	22	23
5006	93	69	36	31	26	0	0	39
7001	0	0	34	39	101	93	24	7
7002	36	75	68	87	113	58	0	0
7003	79	86	73	74	72	19	0	0
7004	103	93	62	50	35	0	0	20
7005	109	95	35	15	0	0	0	53
7006	88	49	17	0	25	32	39	64
7007	72	0	0	0	51	70	72	73
7008	64	23	0	0	69	80	56	57
7009	36	25	20	0	0	40	48	43
7010	0	10	17	18	30	29	10	7
7011	23	28	23	13	19	20	0	0
7012	29	32	0	0	0	0	0	0
7013	23	32	0	0	13	23	18	14
9001	0	45	84	84	67	50	25	0
9002	11	71	68	10	0	0	0	0
9003	69	106	91	27	13	0	0	0
9004	92	100	27	0	0	22	62	72
9005	0	98	111	62	23	16	0	0
9006	99	113	62	15	0	0	0	70
9007	121	77	57	0	0	14	77	129

gaging site by comparing the maximum and minimum instantaneous levels recorded each month with its monthly mean level. Short-period fluctuations thus determined at six gaging stations are summarized in Table 11–37. It should be noted that surges may be so localized and relatively short that the nearest water level recording gage may not even detect sudden fluctuations. Such was the case during June 1954 at Montrose Harbor, Chicago, when the nearest water level recording station at Calumet Harbor, 22 miles south of Montrose Harbor, experienced no significant rise in levels.

8.4 Sample Computation of Ultimate Water Level

The following provides a sample computation of one ultimate water level elevation for Reach 3003 at Cleveland, Ohio.

X_1 = recorded monthly level at Cleveland
X_2 = recorded storm water level, maximum instantaneous level at Cleveland
X_3 = basis-of-comparison monthly Lake Erie level
X_4 = basis-of-comparison storm water level
X_5 = depth of water at breaking
X_6 = wave height at breaking
X_7 = deepwater wave height derived from hourly wind data recorded at Cleveland during the 24 hours before time of maximum instantaneous level
X_8 = deepwater wave period corresponding to X_7 (seconds)
X_9 = wave height used to compute run-up being the lesser of X_6 and X_7
X_{10} = representative beach slope of reach
X_{11} = run-up calculated from X_8, X_9, and X_{10}
X_{12} = ultimate water level being the basis-of-comparison storm water level plus the run-up

The wave run-up is calculated on the basis of the following equation:

$$X_{11} = 2.3\,(X_{10})\,(X_8)\,(X_9)^{0.5} \qquad (11)$$

The maximum height at breaking is given by the equation:

$$X_6 = X_5 + 1.28 \qquad (12)$$

where $X_5 = X_4 -$ (lake elevation on IGLD [1955]) and

$$X_4 = X_3 + X_2 - X_1 \qquad (13)$$

Investigators got the following results for one reach of Lake Erie where the basic condition was: X_1=570.33; X_2 = 573.10; X_3 = 570.97;

X_1 =	570.33	X_7 =	22.0
X_2 =	573.10	X_8 =	10.0
X_3 =	570.97	X_9 =	4.02
X_4 =	573.74	X_{10} =	0.125
X_5 =	5.14	X_{11} =	5.74
X_6 =	4.02	X_{12} =	579.48

TABLE 11-37 Short-Period Fluctuations in Feet

Gage Location and Period	Recorded Maximum Rise	Rise for One-Year Recurrence Interval	Recorded Maximum Fall	Fall for One-Year Recurrence Interval
Lake Superior at Marquette (1903-1968)	2.8	1.3	3.2	1.3
Lake Michigan at Calumet Harbor (1903-1968)	3.5	1.8	3.6	1.7
Lake Huron at Harbor Beach (1902-1968)	2.5	0.9	2.0	1.1
Lake Erie at Toledo (1940-1968)	5.3	3.1	7.5	4.6
Lake Erie at Buffalo (1900-1968)	8.2	4.9	4.7	2.4
Lake Ontario at Oswego (1933-1968)	2.2	0.9	1.7	0.9

Section 9

SHORELINE DELINEATION OF PRIVATE AND PUBLIC RIGHTS ON THE GREAT LAKES

9.1 General

Each of the States bordering the Great Lakes has title to the beds of these Lakes, extending to the international or adjacent State boundaries. Likewise, the riparian owner has certain rights to develop his lake frontage, subject only to statute or common law of each State. Appendix 12, *Shore Use and Erosion*, deals with Great Lakes shoreland usage and erosion problem areas.

In defining the shoreward limits of the Great Lakes, most States have certain rules or statutes differentiating private and public rights. In some states the low water mark is the boundary, while in others the ordinary high water mark controls. This separation is not too important for small riparian docks but becomes extremely important in attempting to properly evaluate the effects of dredging or filling on the shoreline and adjacent waters. In Michigan, for example, the ordinary high water mark has been used in connection with its administration of the Great Lakes Submerged Lands Act. Lakeward of this contour the State has authority over dredging and the placement of fills and commercial-industrial structures. Landward of this contour the riparian has absolute ownership and trespass control between it and the water's edge. Recently, the Michigan legislature pegged the ordinary high water mark at an exact level based on International Great Lakes Datum for each of its Great Lakes. Their experience indicates that it is much easier to protect the shoreline from unlawful encroachments, especially in marshy areas with valuable wildlife interests, by using a stated level or fixed elevation.

9.2 Statutes or Legal Interpretations

9.2.1 Illinois (Lake Michigan)

Common law states that "the line at which the water usually stands when free from disturbing causes, is the boundary of land . . . for Lake Michigan as a line (Seaman vs. Smith, 24 Ill. 521)."

9.2.2 Indiana (Lake Michigan)

No statute or common law decisions exist concerning shoreline separation between private and public rights. Generally, it assumes that the ordinary high water mark, as used in Federal court cases, would control.

9.2.3 Michigan (Lakes Erie, Huron, Michigan, St. Clair, and Superior)

Act 247, P.A. 1955, as amended, cites the ordinary high water mark in feet IGLD (1955) for each Lake as: Erie, 571.6; Michigan-Huron, 579.8; St. Clair, 547.7; and Superior, 601.5. Michigan courts, in defining the rights and interests of the State of Michigan as proprietor or trustee of the waters and submerged lands of Lake St. Clair, treat that lake as a Great Lake.

The respective rights of the State and littoral or riparian owners in the Lake are determined in accordance with the same principles, precedents, and laws applicable to the remaining Great Lakes.

9.2.4 Minnesota (Lake Superior)

Common law states that the riparian has absolute title to ordinary high water mark, with a qualified fee to low water mark. The State may make use of area between ordinary high water mark and ordinary low water mark for public purposes, or as an aid to navigation without compensation to the riparian.

9.2.5 New York (Lakes Erie, Ontario)

According to common law the State owns the bed of the Great Lakes up to mean low water line (Wood vs. Maitland, 169 Misc. 484; modified, 259, App. Div. 796). The State has determined mean low water level to be 245.0 feet (USGS) on Lake Ontario. Subtract 1.24 feet from USGS to obtain IGLD (1955) at Rochester, New York. Table 11–6 gives datum conversion factors at other sites.

9.2.6 Ohio (Lake Erie)

Sections 123.03 and 123.031, Ohio Revised Code, state that,

> the waters of Lake Erie, consisting of the territory within the boundaries of the State, extending from the southerly shore of Lake Erie to the international boundary line between the United States and Canada, together with the soil beneath and their contents, do now and have always, since the organization of the State of Ohio, belonged to the State as proprietor in trust for the people of the State.

Territory means the waters and lands presently underlying the waters of Lake Erie and lands formerly underlying the waters of Lake Erie and now artificially filled, between the natural shoreline and the harbor line or line of commercial navigation where no harbor line has been established.

9.2.7 Pennsylvania (Lake Erie)

Ch. 13, 55–362, 363, cites the low water mark as the boundary.

9.2.8 Wisconsin (Lakes Michigan and Superior)

No specific statute exists for the legal contour separating publicly owned lake bed from privately owned upland on the Great Lakes. The court has indicated that a delineation based on the limits of terrestrial vegetation be used.

9.3 Conclusion

It is generally considered necessary to establish a permanent elevational boundary for the Great Lakes shoreline in order to protect it against unlawful encroachments. The boundary separation between private and public rights, related to a specific lake level elevation, assists in managing Great Lakes shoreline resources.

Section 10

GREAT LAKES BASIN PROBLEMS AND NEEDS

10.1 General

General information dealing with levels and flows of the Great Lakes-St. Lawrence River system will be included in this section (Figure 11-40).

The International Joint Commission Study on the Regulation of the Great Lakes Levels is investigating the possibilities of regulating further the levels of the Great Lakes in the best public interest. Presently the IJC study is considering only the existing Great Lakes water supplies with no new diversions into the Basin. An agency of the Canadian government is investigating the possibilities of new diversions of water into the Great Lakes Basin from Canadian sources. This agency will report directly to the Canadian government. It is Canada's prerogative to determine diversion of Canada's surplus water. Only after Canada has prepared facts concerning quantities, delivery points, and costs can studies be made to establish alternatives for supplementing present Great Lakes water supplies from Canada.

10.2 Climate and Meteorology

Most of the Great Lakes shoreline areas need more meteorological stations to get more exact data. These data are essential for studies and design of shore protection, harbor facilities, and flood plain and shore erosion information. Wind, wave, and water current data are essential for proper design.

In computing general ultimate water level data as described in Section 8, much of the wind data were recorded at meteorological stations some distance away from the shoreline. For reaches with no established wind station, the nearest wind station was used.

General recommendations at this time would be to establish a minimum meteorological station network coinciding with the present water-level gaging network. The meteorological station at the shoreline would provide adequate data for correlation with the water-level data recorded there.

The only water-level gage sites where meteorological data are taken are gages located near U.S. Coast Guard Stations. Coast Guard Stations usually do not record wind data continuously, but they observe and log visual readings when intense winds occur. The immediate recommendation would be to implement a program for continuous recording of wind data at all Coast Guard Stations to provide necessary data at Great Lakes shoreline locations. An optimal program for establishing meteorological station networks along Great Lakes shorelines should then consider the present gaps, problem areas of erosion, and areas of potential harbor development. Instrumentation should be easily adaptable to computer processing.

The future of climate modification should be considered. The impact of such long-term trends on Great Lakes water supplies should also be considered.

10.3 Surface Water Hydrology

There is a general concern in a number of planning subareas throughout the Basin that impoundment on streams of tributary basins will affect lake levels. The continuation of such practice may affect base flow and possibly increase maximum water temperature ranges. This in turn will reduce or destroy a stream's coldwater fishing values. Increased impoundments may also cause more evaporation losses.

Planning for impoundments must consider the long-term effects on Great Lakes levels. Based on data provided in Appendix 14, *Flood Plains*, Appendix 6, *Water Supply—Municipal, Industrial, and Rural*, Appendix 21, *Outdoor Recreation*, and Appendix 18, *Erosion and Sedimentation*, the Plan Formulation Report provides cumulative assessment of estimated losses of water supply to the Great Lakes resulting from each Lake's tributary storage and related increased evaporation losses.

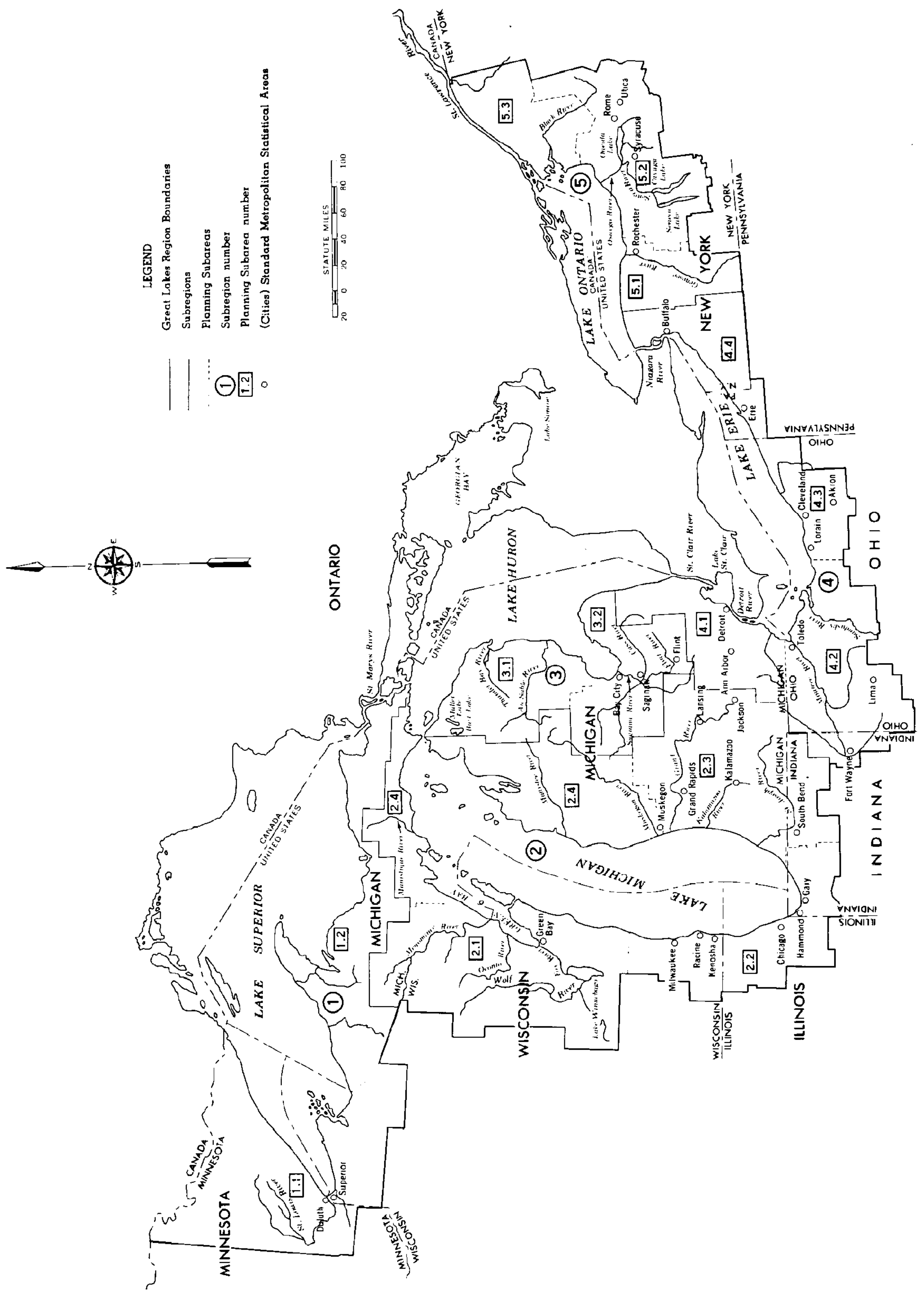


FIGURE 11–40 Great Lakes Region Planning Subareas

10.4 Consumptive Losses of Water

Consumptive loss refers to that portion of water withdrawn from the Basin and not returned. Present estimates for consumptive losses of water from the Great Lakes and projected future losses have been identified in the Framework Study. Previously, the most recent (1965) estimates of consumptive losses were in a report by the Regulation Subcommittee, International Great Lakes Levels Working Committee. Estimated consumptive losses from Lakes Michigan-Huron were 1,249 cfs. These losses lower Lakes Michigan-Huron by approximately 0.1 foot. Table 11–38 presents the reported effects of the United States and Canada consumptive use estimates for 1965 on Great Lakes water levels.

The effect in 1965 on Lake Ontario outflow was a reduction in the average flow of the St. Lawrence River of 2,269 cfs.

The Regulation Subcommittee's report further states that total U.S. consumptive loss for all Lakes was 1,872 cfs in 1965. This is projected to increase to 10,900 cfs by 2020. Canadian consumptive loss for all the Lakes was estimated at 398 cfs in 1965 and is projected to increase to 2,600 cfs by 2020.

Table 11–39 portrays the estimated present and projected future losses due to water supply, power, irrigation, and mineral resources from the United States portion of the Great Lakes. These figures have been estimated for each Lake individually and do not include the lowering effect of one Lake on Lakes lower in the Great Lakes system.

The values in Table 11–39 for 1970 under the U.S. irrigation heading were extrapolated from consumptive losses derived by using 75 percent of projected irrigation water needs for crops and golf courses.

The losses listed for U.S. power are based on the assumption of flow-through cooling (Case I) except for known supplemental cooling (Case II) systems. Consumptive losses for power assuming all supplemental-cooling except for known flow-through systems are also shown in Appendix 10, *Power.* These latter losses are also shown in Table 11–40.

The losses summarized in Table 11–41 are based on the Case I U.S. power losses listed in Table 11–39. Except for 1970 values, Table 11–41 values would all be larger were the Case II power losses used.

Adjusted data for Canada are shown in Table 11–42. Total consumptive losses on the Canadian portion of the Basin for the projected years were derived using the same reference source. These losses and the total losses on the U.S. portion are shown in Table 11–43. The effects of consumptive losses on lake levels in 1970 are listed in Table 11–44.

The effect in 1970 on the Lake Ontario outflow was estimated to reduce the average flow of the St. Lawrence River by 3,328 cfs. The estimated consumptive use values for 1970 were approximately 40 percent greater than for 1965 as determined by the International Great Lakes Levels Working Committee.

Consumptive use of water reduces a lake's water levels and levels of all lakes downstream. Regulation of Lakes Superior and Ontario is conducted within given stage limits, so the effects are indeterminate. To maintain these limits with a reduced water supply because of consumptive use requires reducing outflow from each of these Lakes.

10.5 Shore Use and Erosion

For planning purposes those intending to build along the Great Lakes shoreline must know the full range of lake level fluctuation to which that segment of shoreline may be subjected. Studies have developed ultimate storm water level data on a general reach basis for the International Joint Commission's study and adapted them to suit the shorelines of the Great Lakes. This appendix provides these data for United States reaches. Such general storm level data should be applied with caution, because no field verification has been performed. Users of these data must be alerted to this limitation. The method for computing ultimate water level data is described in Section 8.

TABLE 11–38 Effect of Consumptive Use on the Great Lakes for 1965

Lake	Consumptive Use (cfs) By Basin	Consumptive Use (cfs) Cumulative	Ultimate Effect (feet)
Superior	38	38	---[1]
Michigan-Huron	1249	1287	-0.1
Erie	682	1969	-0.1
Ontario	300	2269	---[1]

[1]Indeterminate--Lake is regulated

TABLE 11–39 Consumptive Losses—Present and Projected in Cubic Feet per Second

	Year	Superior	Michigan	Huron	Erie	Ontario
U. S. Power						
	1970	6	68	9	137	34
	1980	5	154	66	127	68
	2000	37	522	209	416	95
	2020	80	1145	464	814	186
U. S. Mineral						
	1968	84	4	3	18	8
	1980	136	4	4	28	11
	2000	203	8	6	57	21
	2020	300	12	11	119	43
U. S. Water Supply Municipal						
	1970	7	295	16	250	53
	1980	8	377	23	343	61
	2000	12	577	44	508	98
	2020	16	817	70	726	139
U. S. Water Supply Industrial						
	1970	17	721	28	412	48
	1980	23	989	48	585	68
	2000	52	1994	148	1448	158
	2020	94	4084	428	3472	384
U. S. Water Supply Rural						
	1970	5	116	18	61	35
	1980	5	141	25	73	42
	2000	6	182	34	92	50
	2020	6	219	45	114	60
U. S. Irrigation						
	1970	3	200	30	100	23
	1980	4	254	32	134	31
	2000	7	380	45	204	55
	2020	9	517	67	284	82

TABLE 11–40 U.S. Power Consumptive Losses in Cubic Feet per Second (Case II)

Year	Superior	Michigan	Huron	Erie	Ontario
1970	6	68	9	137	34
1980	6	216	86	148	68
2000	59	822	318	641	97
2020	128	1807	730	1300	223

TABLE 11–41 U.S. Consumptive Losses—Present and Projected in Cubic Feet per Second (Case I)

Year	Superior	Michigan	Huron	Erie	Ontario	Total
1970	122	1404	104	978	201	2809
1980	181	1919	198	1290	281	3869
2000	317	3663	486	2725	477	7668
2020	505	6794	1085	5529	895	14808

TABLE 11–42 1970 Consumptive Losses—U.S. and Canada in Cubic Feet per Second

	Superior	Michigan Huron	Erie	Ontario	Total
U.S.	122	1508	978	201	2809
Canada	9	57	166	287	519
Total	131	1565	1144	488	3328

TABLE 11–43 Present and Projected Consumptive Losses—U.S. and Canada

	1970	1980	2000	2020
Canada	519	784	1431	2180
U.S.	2809	3869	7668	14808
Total	3328	4663	9099	16988

TABLE 11–44 Effect of Consumptive Use on Great Lakes Levels

Lake	Consumptive Use (cfs) By Basin	Consumptive Use (cfs) Cumulative	Effect On Lake Levels (feet)
Superior	131	131	---[1]
Michigan-Huron	1565	1696	-0.1
Erie	1144	2840	-0.1
Ontario	488	3328	---[1]

[1]Indeterminate--Lake levels are regulated

10.6 Water Level Disturbances

Because of their larger size, the Great Lakes experience unusual phenomena which normally do not occur on smaller bodies of water.

10.6.1 Seiches

A seiche or surge is an oscillation of the lake water surface. Wind and barometric pressure are the two most common causes. Wind-produced seiches follow cessation or shift of wind after a period of relatively steady wind direction. Atmospheric pressure changes may also change lake levels.

Severe disturbances of lake levels formed by the combined action of the intense pressure gradient and strong winds have occurred in various portions of the Great Lakes. The most severe effects are experienced at shallow water shorelines or bays.

The most prominent seiche in Lake Michigan produced a sudden and unexpected rise in lake level at Montrose Harbor (Chicago) on June 26, 1954, causing several drownings. Investigations of such surges show that they are caused by intense squall lines that move rapidly across the southern portion of Lake Michigan in a southeasterly direction. Other Great Lakes localities have experienced this type of water level disturbance.

10.6.2 Harbor Resonance

Harbors may exhibit large oscillations due to resonance within the harbor generated initially by external fluctuations. Local harbor resonance, progressive within the harbor, may produce water levels higher within the harbor than in the lake. Piers, docks, or small inlets may amplify resonance within the harbor. These sudden disturbances can sometimes result in navigation hazards. Hazardous currents at harbor entrances are frequent especially during storms at such places as Calumet Harbor (Illinois) on Lake Michigan, and Conneaut and Ashtabula Harbors on Lake Erie.

10.7 Diversion from Lake Michigan at Chicago

This diversion affects the levels of Lakes Michigan, Huron, and Erie and decreases inflow to Lake Ontario. Only Lake Superior is not affected. The authorized diversion from Lake Michigan at Chicago is limited to 3,200 cubic feet per second (U.S. Supreme Court decree effective March 1970).[48] This diversion, described in more detail in Subsection 12.6, includes water from the Lake Michigan drainage basin that normally would flow into the Lake as well as water diverted directly from the Lake. The Chicago Sanitary and Ship Canal has a sustained capacity for diverting up to 8,500 cfs. Approval for additional diversion amounts up to 8,500 cfs was granted by the U.S. Supreme Court during the period December 17, 1956, to February 28, 1957, to alleviate low water conditions on the Mississippi River. One might also materially alleviate extreme high lake level conditions on Lakes Michigan, Huron, and Erie by increasing the Chicago diversion on a temporary, emergency basis. Objections to increasing this diversion are well-known as the result of the U.S. Supreme Court Report of Albert B. Maris, Special Master, dated December 8, 1966. During periods of higher diversion flows (such as December 17, 1956, to February 28, 1957) some problems in local navigation operations on the Illinois Waterway occurred.

10.8 Policy Relating to Transferring Water

The City of Detroit constructed a water supply intake facility at the lower end of Lake Huron that initiated operation in 1973. The intake has a capacity of 1,250 cubic feet per second, with average withdrawals somewhat less. The unconsumed portion is returned to the Great Lakes system at Lake St. Clair and the Detroit River. Detroit's facility will also supply the City of Flint, with Flint's unused portion being returned to the Saginaw River. The major portion of the water withdrawn bypasses the St. Clair River and Lake St. Clair. Legal policy or regulating statutes should be considered for controlling similar situations which in themselves may not significantly affect lake levels and flows but cumulatively may have a substantial effect on the Great Lakes.

10.9 Ogoki-Long Lake Diversions

The Long Lake Project was started for log-driving purposes in 1939 and for power development in 1941. The Ogoki Project, in 1943, initiated diversion of water from the Albany River watershed (Hudson Bay) into the Lake Superior basin. A detailed description of these diversions appears elsewhere in this report.

An exchange of notes in October and November 1940 between the governments of the United States and Canada provided for 5,000 cubic feet per second annually for the combined Ogoki and Long Lake diversions. In recent years, annual amounts diverted have exceeded this amount by approximately 20 percent. In late 1969, as a result of an inquiry from a State bordering on the Great Lakes concerning the higher quantities being diverted in recent years, the U.S. Section of the International Joint Commission asked the U.S. Department of State to clarify the intent of the exchange of notes on this matter.

The provisions of the Treaty of 1950 concerning uses of waters of the Niagara River do not include allocation of the waters that the Ogoki-Long Lake projects divert into the Great Lakes system. The 5,000 cfs is for Canada's use for power production purposes at Niagara. The remaining Lake Erie outflows not required to flow over the Niagara Falls are equally divided for U.S. and Canadian power production purposes. Further description of the implementation of this Treaty appears later in this appendix. Authorities modified the rule curve used for determining monthly Lake Superior outflow in 1955 to allow for the increase in supply to the Lake due to these diversions.

Section 11

LAKE SUPERIOR PROBLEMS AND NEEDS

11.1 General

This section presents information on problems and needs related to levels and flows of Plan Area 1 (Lake Superior) which consists of two planning subareas (Figure 11-41).

11.2 Fluctuations of Lake Superior

Seasonal and long-term variations in Lake Superior water levels have been recorded since 1860. Based on these records, the difference between the highest monthly mean of 602.06 feet, which occurred in August 1867 and the lowest monthly mean of 598.23 feet, which occurred in April 1926 at Marquette, Michigan, is 3.83 feet. The greatest annual fluctuation as shown by the highest and the lowest monthly mean of any year was 2.14 feet, and the least annual fluctuation was 0.41 foot. The maximum recorded short-period rise at Marquette, Michigan, for the period 1902–1968 was 2.8 feet. Investigators obtained this value by comparing the maximum instantaneous level recorded at this locality with its monthly mean level. Regulation of Lake Superior since 1921 has modified extreme fluctuations.

Wind is the primary cause of oscillations in Lake Superior. The Lake's most recent severe variation was on June 30, 1968, when a seiche produced a reported level variation of five to six feet above normal at one spot near the Keweenaw Peninsula. Local harbor resonance, progressive within the harbor, may produce water levels higher within the harbor than in the Lake. Marquette Harbor and Little Lake Harbor (smallcraft harbor refuge), Michigan, have experienced these conditions. Piers, docks, or small inlets may amplify resonance within the harbor. These sudden disturbances can sometimes cause navigation hazards.

11.2.1 Regulation of Lake Superior

Lake Superior has been regulated since the completion of control works at the head of the rapids in the St. Marys River in 1921. The International Lake Superior Board of Control was established pursuant to Orders of Approval issued by the International Joint Commission on May 26 and 27, 1914, to supervise the regulation of Lake Superior. The membership of the two-member board is shown in Figure 11-70.

This Board directly supervises the operation of the river control works and the power canals, as related to the flows in the canals. It is charged with maintenance of Lake Superior water levels, as nearly as possible, between elevations 600.5 and 602.0 feet IGLD (1955). In addition, outflow is controlled to prevent the level of the St. Marys River below the locks from rising above 582.9 feet. To guard against unduly high stages in the lower St. Marys River, any discharge exceeding what would have occurred at a like stage of Lake Superior prior to 1887 is restricted, so that the elevation of the water surface immediately below the locks will not exceed 582.9 feet. The Board regulates the rate of outflow from Lake Superior in accordance with the plan of operation which meets these criteria, by opening and closing gates of the 16-gate control structure at Sault Ste. Marie, Michigan. Figure 11-42 is an aerial view of the control structure.

A physical factor that severely limits the results obtainable from regulating Lake Superior is St. Marys River's relatively small capacity to discharge water from the Lake as compared to the large amount that sometimes comes into the Lake. Hydrologic and hydraulic factors are such that during the late spring and summer, the net amount of water entering the Lake normally exceeds the outlet discharge capacity. During the spring and summer months of a rainy year, the largest monthly net supply may be nearly three times the outlet capacity, as it was in 1968.

The maximum discharge capacity of the St. Marys River is considerably greater than it was, due to deepened navigation channels in the river and to the power canals at Sault Ste. Marie. With all the gates open and with the

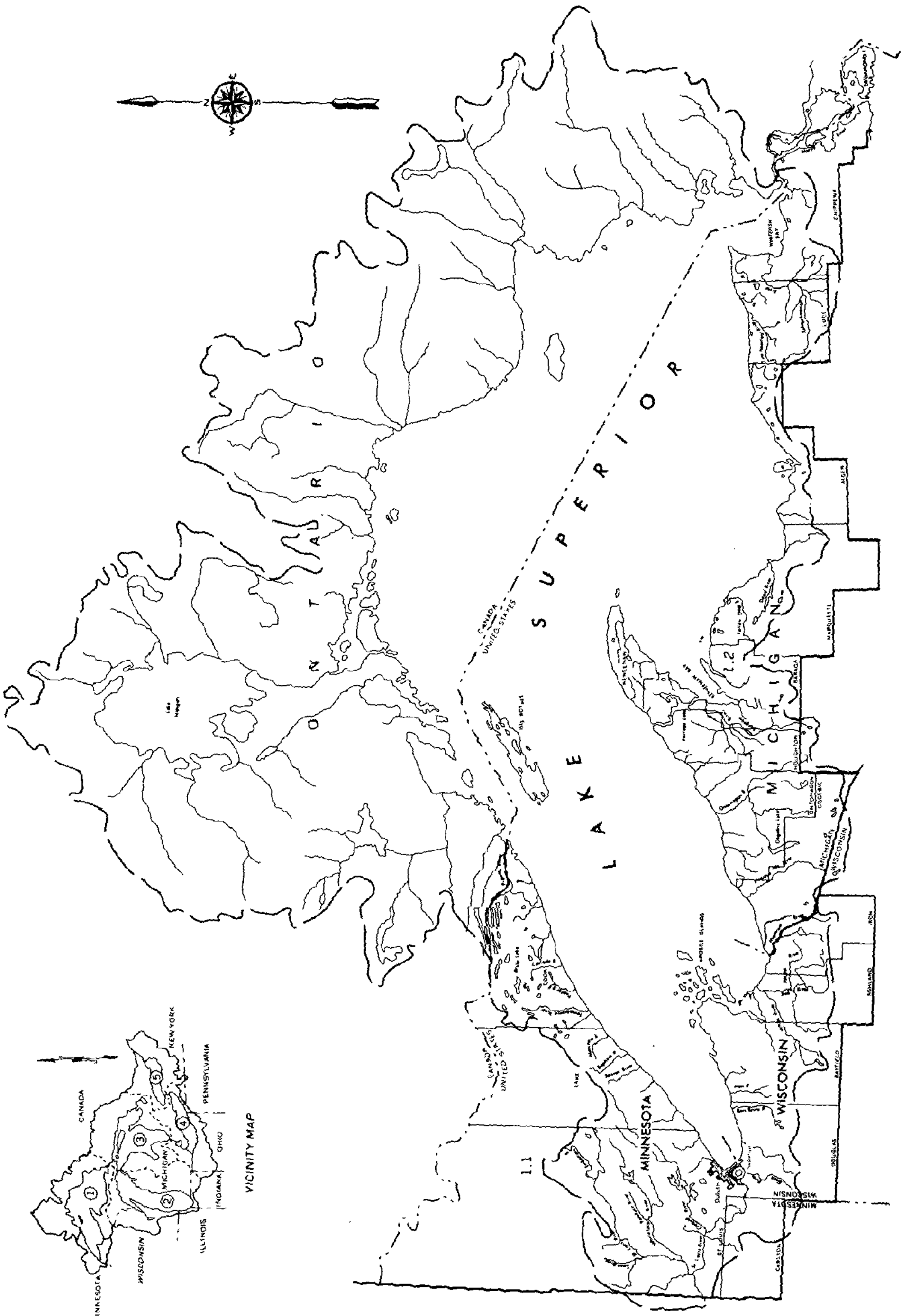


FIGURE 11–41 Plan Area 1

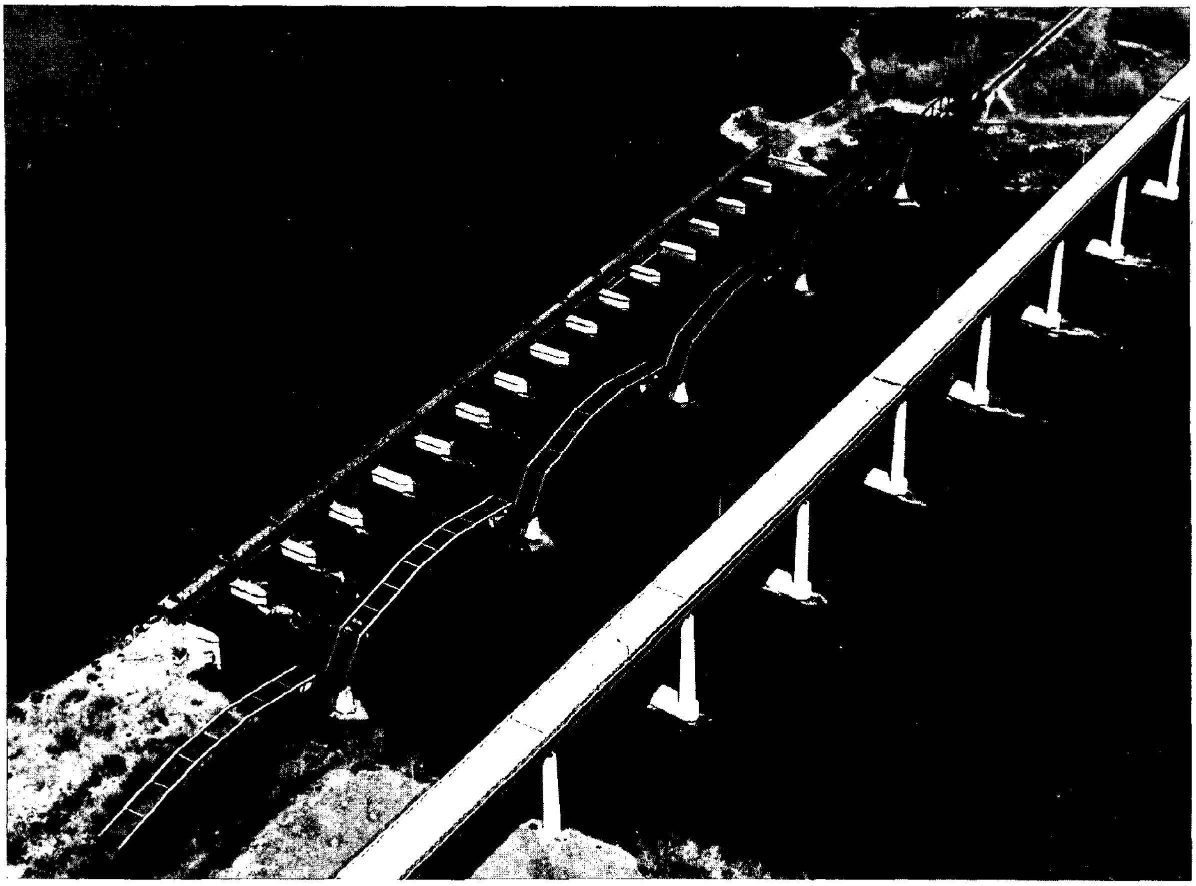


FIGURE 11-42 Aerial View of Control Structure—Sault Ste. Marie

flows through the power canals, when necessary more water can be discharged from the Lake than under natural outlet conditions.

The minimum gate setting is ½ gate open in the structure to maintain sufficient flow in the river immediately below the structure to preserve acceptable conditions for fish. As recently as 1957 the U.S. power diversions were curtailed in order to adhere to minimum rule curve outflow requirements when Lake Superior levels were very low. Union Carbide Company, the predecessor to Edison Sault Electric Company, lost money due to flows that were insufficient to maintain manufacturing processes.

Additionally, the International Lake Superior Board of Control used discretionary authority during the period April-December 1964 to deviate from the regulation plan and release water in excess of rule curve requirements. This was considered appropriate because while Lake Superior had supplies much above normal, the downstream Lakes, particularly Lakes Michigan and Huron, were at or near all-time low levels. The International Joint Commission approved the discretionary authority releases. By the end of 1964, more than 74,200 cfs-months were discharged. As a result, at the end of 1964, the levels of Lakes Michigan and Huron were 0.14 foot higher than they would have been without the extra inflow.

As part of the joint Canada-United States study of the water levels of the Great Lakes, an investigation of the feasibility of increasing the present 85,000 cfs regulated maximum winter outflow from Lake Superior is under way. Under past discharge conditions this restriction had considerable merit. At this flow a good ice cover could be formed in the river, thus reducing the production of anchor and frazil ice, and consequent ice jams. Because of recent channel improvements in certain narrow reaches of the St. Marys River, it can possibly carry higher flows during winter without causing ice jams. Jams have caused flooding problems when the outflow was allowed to exceed 85,000 cfs in the past. Tests call for the outflow to be increased to about 95,000 cfs. Ability to open and close gates quickly under adverse conditions had to be demonstrated. This was accomplished with the installation of steam-generating equipment and supply lines to de-ice certain gates.

Close surveillance of ice and river levels accompanied the higher flow until the International Lake Superior Board of Control was assured that ice jams would not occur in the river. The aim is to investigate increasing the flexibility of winter outflows in expectation of deriving greater economic benefits. Tests were again carried out in February–March 1970 and December 1970–January 1971. Under conditions during the first two winters, flow tests of 95,000 cfs outflows were successful.

The winter test operation for the 1970–71 winter began on December 16, 1970, with an outflow of 95,000 cfs. But during January a steady increase in the water level was registered at the U.S. Powerhouse tailrace gage. This level was approximately maintained until January 25, at which time a further buildup began, reaching a peak on January 28. As this elevation was approaching the critical level where flooding of generator pits on the U.S. side would occur, the International Lake Superior Board of Control decided to reduce the flow to 85,000 cfs by the closure of three gates. This lowered the water level at the U.S. Powerhouse tailrace gage to an acceptable level on the following day. It is believed that such an anomaly was created by an accumulation of ice under the cover below the rapids.

The navigation season in the St. Marys River was extended until January 30, 1971. This represents almost a three-week extension over the previous year. The season extension complicates analysis of the winter test conducted. It is not known what relationship navigation may have to the difficulties encountered in discharging the 95,000 cfs. Additional flow tests of 95,000 cfs were planned during the winter of 1972 after the 1971 navigation season had ended and a stable ice cover and normal winter slope were present in the St. Marys River. However, these were limited to ice surveillance during the winter of 1972.

11.3 Planning Subarea 1.1

Planning Subarea 1.1 includes the Superior Slope Complex, St. Louis River, Apostle Islands Complex, Bad River, and Montreal River Complex drainage areas (Figure 11–43).

11.3.1 General

Ultimate storm water level data for the Lake Superior shore of Planning Subarea 1.1 were computed utilizing data from locations in Table 11–45.

There are serious problems of shore erosion with some inundation along the entire shoreline of Planning Subarea 1.1. Shores in Wisconsin are essentially clay, sand, and silt, and very erodible. In Minnesota the Lake Superior shoreline, which begins at Minnesota Point and ends at the international boundary, is principally rock with gravel and sand beaches.

The high water levels of 1968, coupled with storm and wind conditions, have seriously eroded most of Lake Superior's shores. The Corps of Engineers, St. Paul District, made a field damage survey to determine the extent of high water damages during August and September 1968 along the Lake Superior shoreline. In addition, damage data were obtained for the November 1968 storm at Saxon River, Wisconsin, and for the December 1968 storm at Two Harbors, Minnesota. Based on the above-mentioned damage survey, estimated losses amounted to \$773,600 in Minnesota and \$428,700 in Wisconsin. Approximately \$270,000 of the damages in Wisconsin were inundation of flooding of properties in Superior Harbor area. In Minnesota, minor erosion damage occurred. Inundation damage in Duluth Harbor was estimated at approximately \$64,000 with \$500,000 damage to a Federal breakwater structure at Two Harbors.

Some rivers in the planning subarea experience severe flooding problems, often complicated by ice jams. The most serious ice jams normally occur at the mouth of a river where littoral drift and lake ice may impede the flow of ice and flood the lower river. Lake level data, including the range and frequency of fluctuations that occur at a locality, are required information for designing channel improvements and harbor structures.

11.3.2 Sedimentation and Tributary Erosion

Sedimentation in streams and rivers of the Lake Superior drainage basin in the northwestern red clay area of Wisconsin has seri-

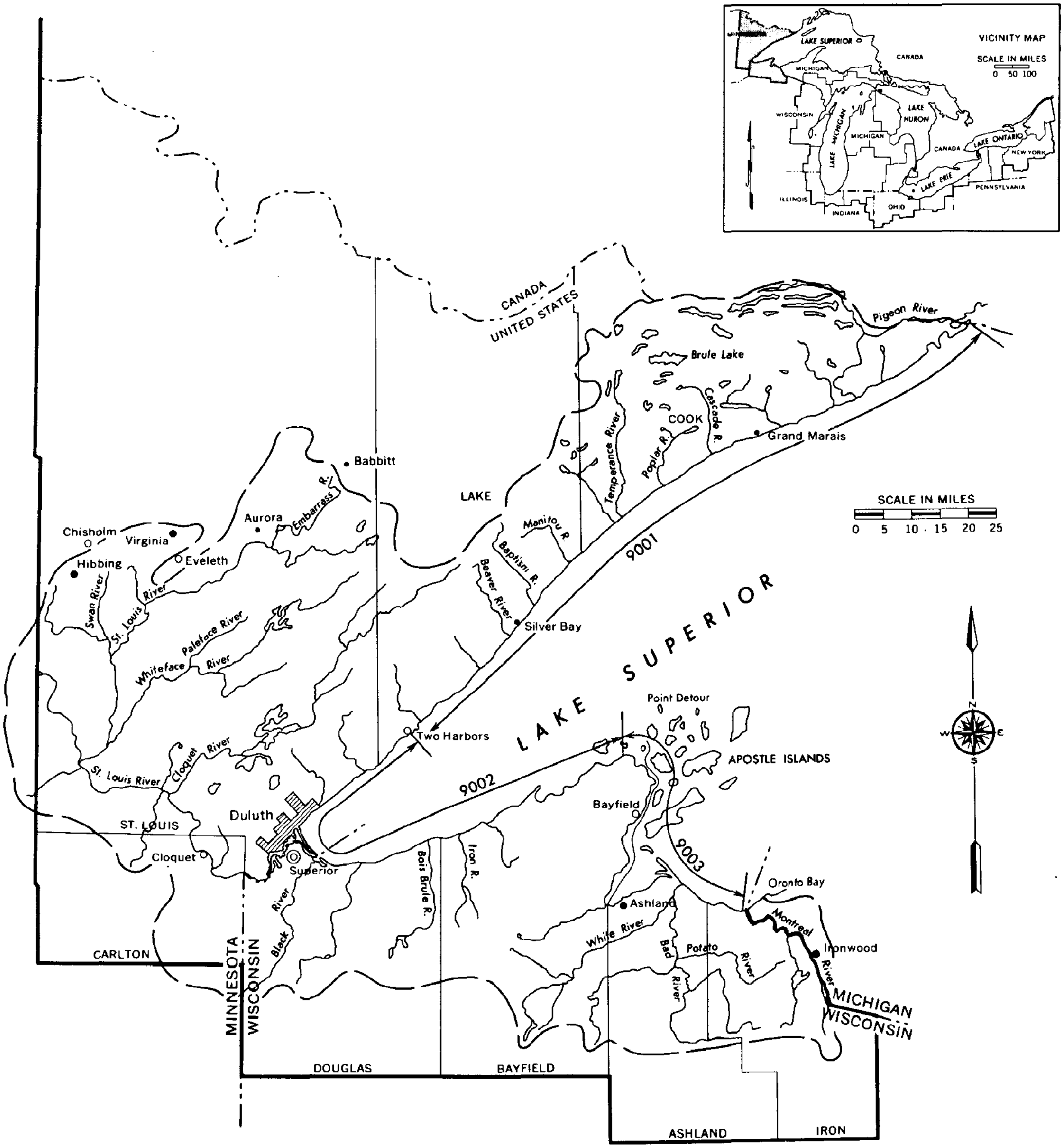


FIGURE 11–43 Planning Subarea 1.1

ously marred the area's scenery and fishing. Streambank erosion is common and is a major source of the sedimentation. The waters of Lake Superior in the near-shore locality of these tributaries become turbid (red clay color) after a rain due to clay sediment carried from interior lands.

11.4 Planning Subarea 1.2

Planning Subarea 1.2 consists of the following drainage areas: Porcupine Mountains Complex, Ontonagon River, Keweenaw Peninsula Complex, Sturgeon River, Huron Mountains Complex, Grand Marais Complex,

TABLE 11-45 Data Stations, Planning Subarea 1.1

Reach of Shore	Weather Station	Water Level Station	Reach No.
International Boundary to Two Harbors, Minn.	Duluth, Minnesota	Two Harbors, Minn.	9001
Two Harbors, Minn. to Point Detour, Wis.	Duluth, Minnesota	Duluth, Minn.	9002
Point Detour, Wis. to Oronto Bay, Wis.	Marquette, Mich.	Marquette, Mich.	9003
Oronto Bay, Wis. to Copper Harbor, Mich.	Marquette, Mich.	Marquette, Mich.	9004

Tahquamenon River, and Sault Complex (Figure 11-44).

11.4.1 General

Ultimate storm water level data for the Lake Superior shore of Planning Subarea 1.2 were computed utilizing data from the locations listed in Table 11-46.

Serious beach and shore erosion problems exist throughout the entire shoreline of Planning Subarea 1.2. The high water levels that occurred in 1968, coupled with storm and wind conditions, seriously eroded most of the U.S. shores of Lake Superior. A field damage survey determined the extent of high water damage during August and September of 1968 along Lake Superior shoreline. In addition, damage data were obtained for the November 1968 storm at Grand Traverse Bay (Keweenaw Peninsula), Michigan. Estimated losses on the Michigan shoreline amounted to $371,000. Principal damages to Michigan shoreline were due to beach and bank erosion. Banks eroded three to four feet in several areas, and beaches suffered considerable damage. The Whitefish Bay and Grand Traverse Bay (Keweenaw Peninsula) areas in particular are subject to high water damage. High water levels accompanied by seiche or storm action result in considerable erosion and often inundation along the shoreline of the planning subarea, where many cabins and summer residences have been built in low areas.

11.4.2 St. Marys River Discharge

The discharge of the St. Marys River during the period 1860-1970 has averaged 74,500 cubic feet per second. The maximum recorded monthly outflow was 127,700 cfs, which occurred in August 1943. The minimum monthly outflow was 40,900 cfs, occurring in September 1955. The swiftest currents in the navigable channels of the St. Marys River are at the Middle Neebish dike, the West Neebish rock cut, and the Little Rapids cut. Velocity of the current depends largely upon the discharge of the river and the elevation of the water surface at the river's mouth. Releases through the navigation and power canals and the compensating works at Sault Ste. Marie control river discharge, so that it varies according to water level requirements of Lake Superior.

When easterly or southerly winds raise the water surface at the upper end of Lake Huron, current velocity is temporarily checked. When the stage on Lake Superior permits a large flow, the current is strong. If the level of Lake Huron is low, it further increases the current.

11.4.3 Filling along St. Marys River

St. Marys River, with its many islands and channels, has experienced considerable filling and dredging along its banks since the area was first developed. While the State of Michigan's Inland Lakes and Streams Act (Act 291 P.A. 1965 as amended) has halted large-scale indiscriminate encroachments, many riparians are still violating the law with smaller projects. The problem is two-fold: lack of sufficient manpower to inspect the countless miles of river shoreline for proper enforcement of dredging and filling laws; and misunderstanding or ignorance by the riparians of Michigan's laws regarding shoreline development.

Additionally, people living outside Michigan own large parts of these shorelines and may lack knowledge of the applicable statutes. This

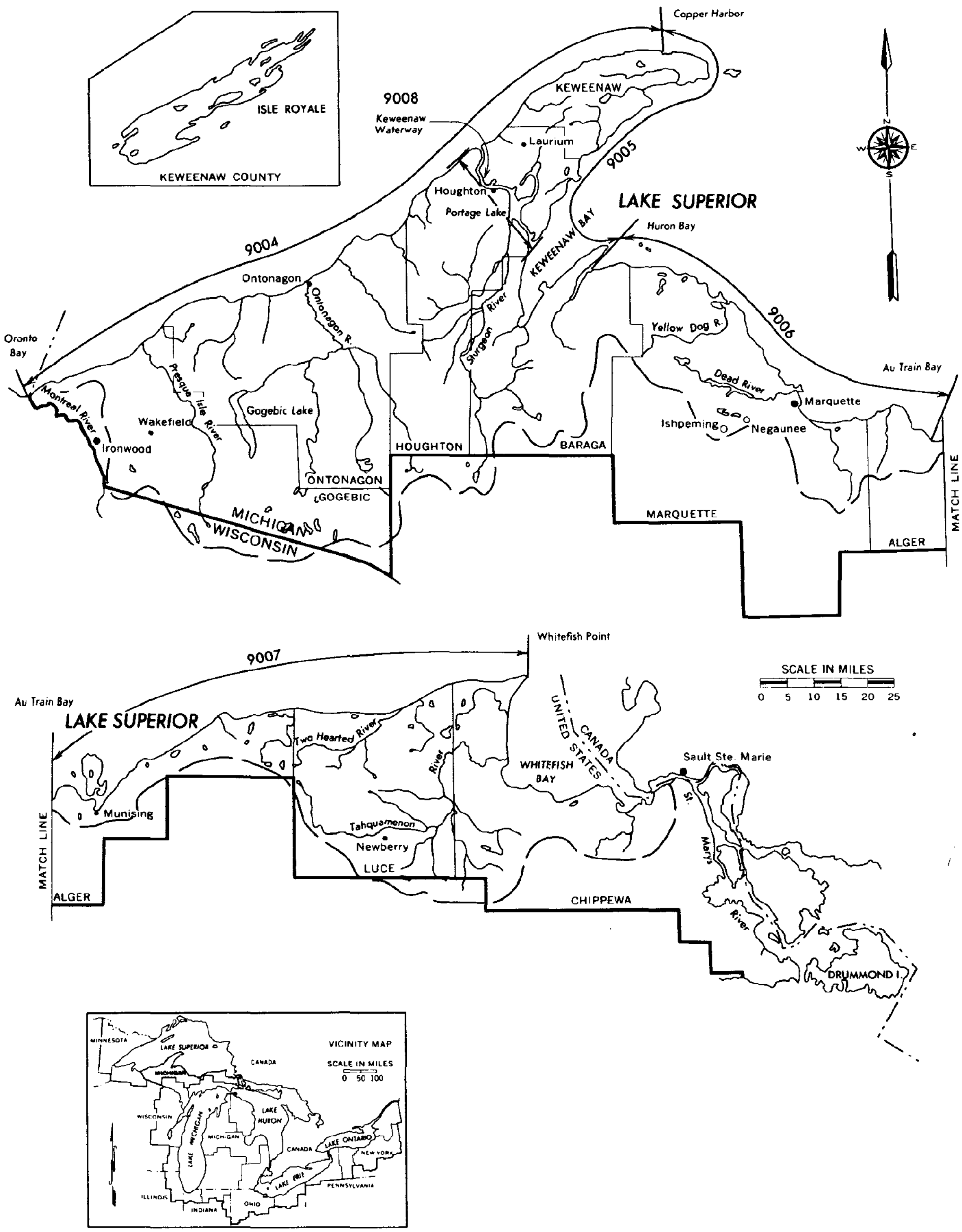


FIGURE 11–44 Planning Subarea 1.2

TABLE 11-46 Data Stations, Planning Subarea 1.2

Reach of Shore	Weather Station	Water Level Station	Reach No.
Oronto Bay, Wis. to Copper Harbor, Mich.	Marquette, Mich.	Marquette, Mich.	9004
Copper Harbor, Mich. to Huron Bay, Mich.	Marquette, Mich.	Marquette, Mich.	9005
Huron Bay, Mich. to Au Train, Mich.	Marquette, Mich.	Marquette, Mich.	9006
Au Train, Mich. to Point Iroquois, Mich.	Marquette, Mich.	Marquette, Mich.	9007
Keweenaw Waterway, Mich.	----	Marquette, Mich.	9008

threat of unauthorized shoreline improvements is important. This area has many small bays and shallow waters which provide valuable fisheries and wildlife habitat, and careless dredging and filling may easily destroy such areas.

11.4.4 Winter Test of Control Structure

The Lake Superior control structure is in the St. Marys River at Sault Ste. Marie, Michigan, 18 miles downstream from Lake Superior. It lies across the river in a north-south direction at a point immediately above the St. Marys Falls, which is by-passed by navigation and power canals on both the United States and Canadian sides of the river as shown in Figure 11-23. The structure consists of 16 steel gates, approximately 52 feet wide, between concrete and masonry piers approximately eight feet wide. The manually-operated machinery is on a deck above the gates, and it requires two men to operate a gate. A photo of the control structure is shown in Figure 11-22.

Because an ice jam occurred in 1916 at a flow of 108,000 cfs, authorities established a maximum winter outflow of 85,000 cfs. Considerable improvements in the navigational channels of the St. Marys River have since been made. Making the channel more efficient has reduced to some extent the probability of ice jams. Ice jams can occur in the restrictions around the Neebish Island channels and at the head of the Little Rapids Section where the river divides and approximately 75 percent of the flow passes through the Little Rapids reach. Very little information is available regarding ice conditions in the St. Marys River. Based upon past experience, precautions can be taken to identify the formation of ice jams. A water level recorder above the section subjected to jams and another below will register an increased difference in level, identifying the onset of ice jamming conditions.

For the winter tests described previously, the U.S. slip gage has been used as the upper monitoring recorder and a gage installed just above Frechette Point has been the lower water level recorder. Figure 11-45 shows the upper St. Marys River, depicting the restricted channels around Neebish Island and the head of the Little Rapid section with the monitoring water level gages. Data from the Frechette Point gage are telemetered to the U.S. slip gage site so that the two water levels can be monitored simultaneously.

In addition to gaging arrangements in the critical sections of the lower St. Marys River, plans have also been made to provide regular ground and air observation of ice formation, and to collect meteorological, hydraulic, and other pertinent data. Under the direction of the Corps of Engineers, Detroit District, a continuous analysis of the data will determine if critical ice jamming conditions are developing.

11.4.5 Legal Demarcation between the St. Marys River and the Great Lakes

The State of Michigan has designated the legal demarcation of the St. Marys River from the Great Lakes for the purpose of administer-

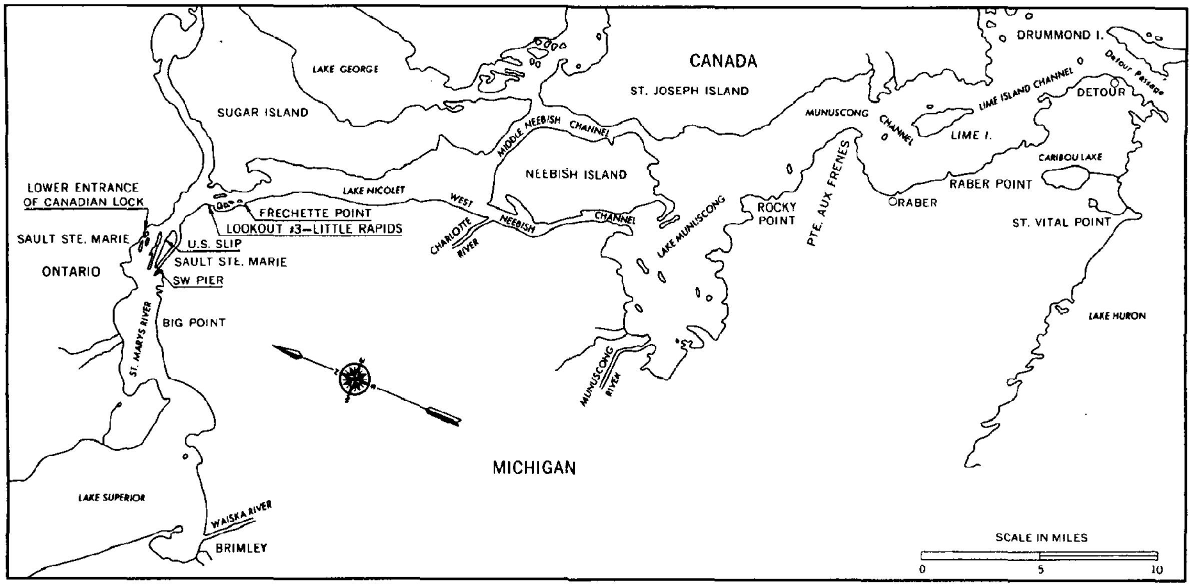
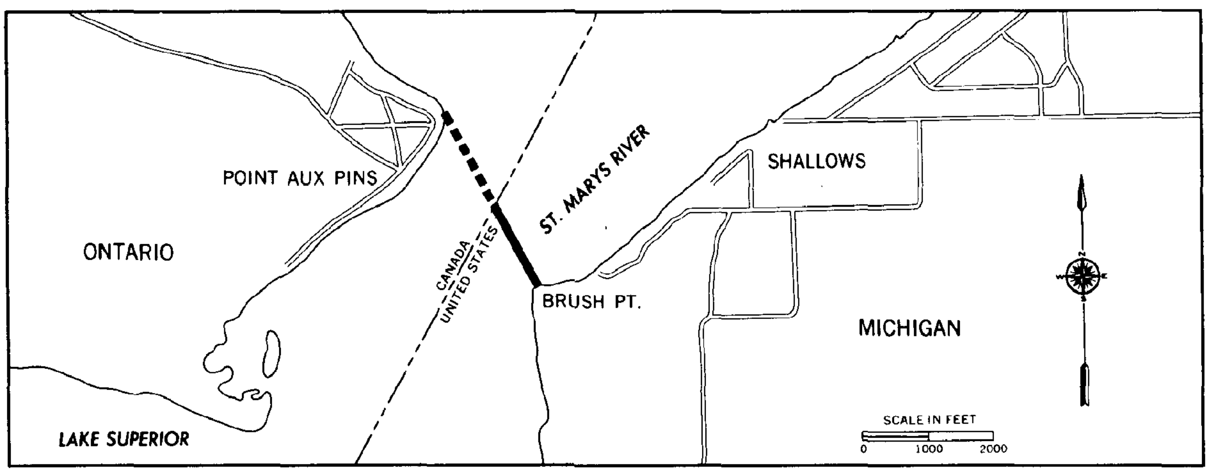
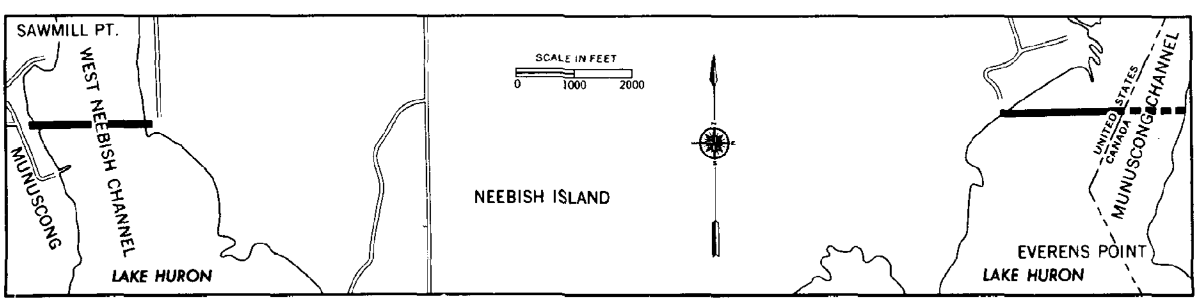


FIGURE 11–45 St. Marys River—Location of Gages



St. Marys River from Lake Superior.



St. Marys River from Lake Huron.

FIGURE 11–46 State of Michigan Legal Demarcation—St. Marys River from the Great Lakes

TABLE 11-47 Water Usage at Sault Ste. Marie in Cubic Feet per Second

Water Usage	cfs
Canada	
Great Lakes Power Company	17,000
Canadian Navigation Lock (during navigation season)	200
U.S.	
Edison Sault Electric Company	30,500
U.S. Hydro Plant	12,800
U.S. Navigation Lock (during navigation season)	1,300

ing appropriate statutes. Figure 11-46 shows the separations between the St. Marys River and Lakes Superior and Huron. The Michigan Department of Natural Resources determined these after considerable study. It is necessary to define boundary areas of inland rivers, which are under Statute Act 291, P.A. 1965, whereas Act 247, P.A. 1955, as amended, applies to Great Lakes water areas. Bottomlands on the river are considered private property of the riparian owner whereas the State of Michigan retains rights over Great Lakes bottomlands.

11.5 Water Usage—Lake Superior Outflow

The present water usage of the Lake Superior outflow at Sault Ste. Marie, Michigan, and Sault Ste. Marie, Ontario, is estimated in Table 11-47. A map depicting these canals, locks and structure is shown in Figure 11-23.

Each month the difference between navigation and power requirements, and the outflow prescribed by the rule curve is discharged through the control structure gates at the head of the rapids.

Under a long-term contract, the Edison Sault Electric Company is obligated to pay the U.S. government annually for the use of water. In 1916 the application by the Michigan Northern Power Company for the first lease was approved for the obstruction, diversion, and use of the waters of the St. Marys River. The present lease, for surplus water available to the U.S. in the St. Marys River between the United States and the Michigan Northern Power Company effective June 22, 1950, was transferred to the Union Carbide Power Company on July 14, 1952, and then to the Edison Sault Electric Company on August 21, 1962.

At the time of this writing, the Power Subcommittee of the International Great Lakes Levels Working Committee has considered operating only existing facilities for the St. Marys River. The relatively low head and small surplus available there make it unattractive for construction of new power developments.

Section 12

LAKE MICHIGAN PROBLEMS AND NEEDS

12.1 General

This section presents information, problems, and needs related to levels and flows of Plan Area 2 (Lake Michigan), which consists of four planning subareas (Figure 11–47).

12.2 Fluctuations of Lake Michigan

The average or normal elevation of the lake surface varies irregularly from year to year. Each year the surface is subject to a consistent seasonal rise and fall, the lowest stages prevailing in winter and the highest in summer. In the 110 years from 1860 to 1969 the difference between the highest (581.94) and the lowest (575.35) monthly mean stages of the whole period at Harbor Beach, Michigan, has been 6.59 feet. Greatest annual fluctuation as shown by the highest and the lowest monthly means of any year was 2.23 feet, and the least annual fluctuation was 0.36 foot. The maximum recorded short-period rise, at Calumet Harbor, Illinois, for the period 1903 to 1969 was 3.5 feet. The value was obtained by comparing the maximum instantaneous level recorded at this locality with its monthly mean level. At Green Bay Harbor, Wisconsin, temporary fluctuations of water levels 2.5 feet above or below the mean lake level may occur.

12.3 Compensation Works in Lakes Michigan-Huron Natural Outlet

As a result of the dredging of the 25-foot and 27-foot navigational projects in the St. Clair and Detroit Rivers, the increased channel cross-sectional areas have caused greater outflows for a given Lakes Michigan-Huron level. The increased channel capacity has resulted in lowering the water levels of Lakes Michigan-Huron seven inches.

The United States has developed plans to compensate for this lowering by structural means which are to be located in the St. Clair River. Canada in 1962[43] agreed in principle to compensation but a specific plan has not been agreed upon. This project has been held in abeyance pending the results of the IJC Study. This is discussed in detail in Subsection 14.4.3.

12.4 Policy Relating to Transferring Water

A legal consideration should be defined to determine a policy relating to transferring water because it is physically possible to transfer water from the Wisconsin River (Mississippi River basin) into the upper Fox River (Lake Michigan basin) at Portage, Wisconsin. Water quality of the Fox River could be improved by such a transfer. Restoring the Portage Canal is the physical means to divert such flow.

12.5 Planning Subarea 2.1

Planning Subarea 2.1 consists of the following drainage areas: Peshtigo River, Pensaukee Complex, Oconto River, Suamico Complex, Fox River, and Sheboygan-Green Bay Complex (Figure 11–48).

12.5.1 General

Ultimate storm water level data for Planning Subarea 2.1 were computed utilizing data from Table 11–48.

Manitowoc and Kewaunee Counties have shorelands with large portions of erodible bluffs. Changes in levels affect these shorelands. The effect of erosion on the bluffs and shorelands increases or decreases as the lake level rises or falls.

A recent channel improvement by the Corps of Engineers has alleviated ice jamming on the Oconto River's restricted channels. Ice jamming problems still exist elsewhere, including tributaries at Fond du Lac and Sheboygan, Wisconsin.

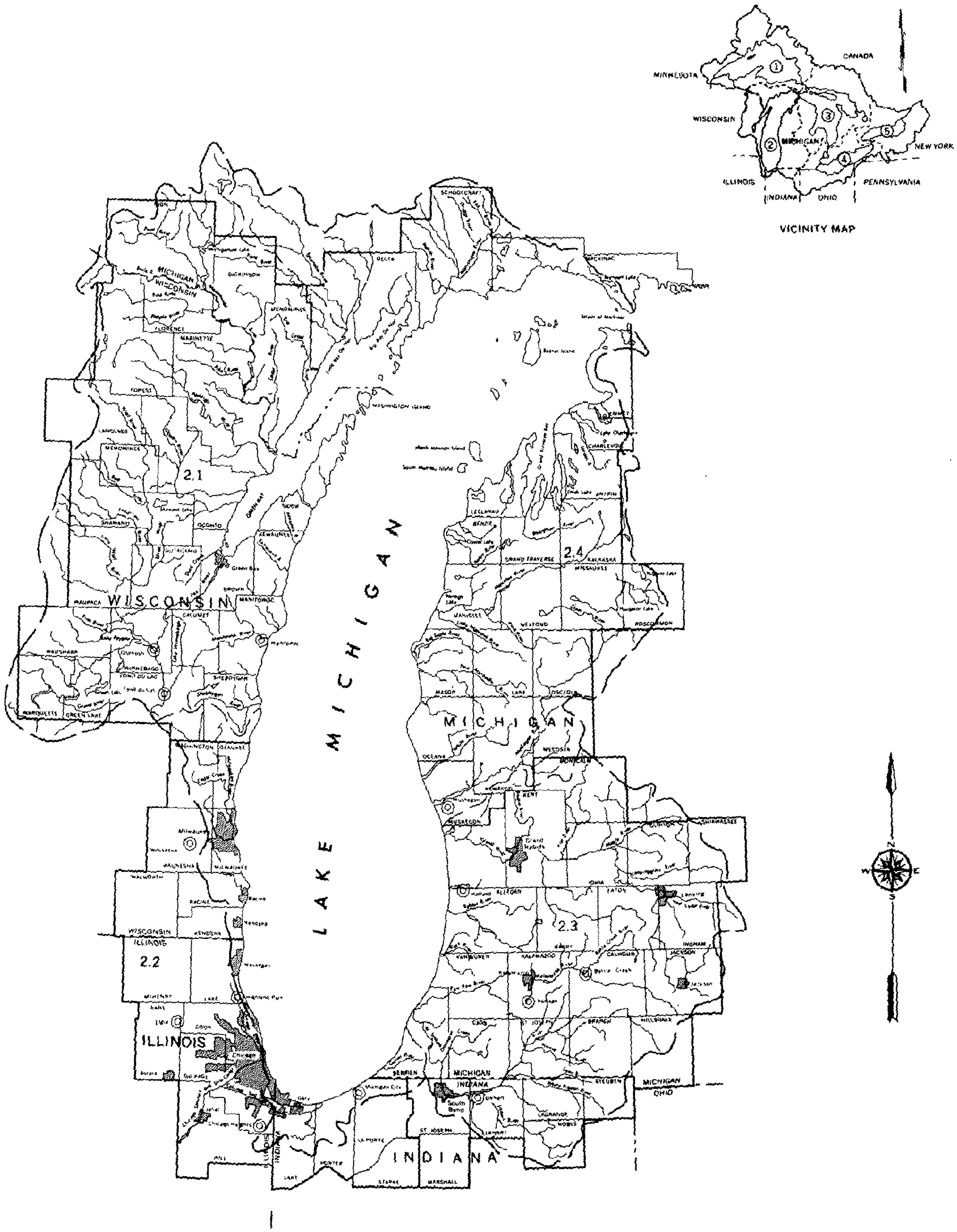


FIGURE 11-47 Plan Area 2

TABLE 11–48 Data Stations, Planning Subarea 2.1

Reach of Shore	Weather Station	Water Level Station	Reach No.
Point Detour, Mich. to Manitowoc, Wis.	Green Bay, Wis.	Sturgeon Bay Canal, Wis.	7002
Manitowoc, Wis. to Milwaukee, Wis.	Milwaukee, Wis.	Milwaukee, Wis.	7003
Escanaba, Mich. to Green Bay, Wis.	Green Bay, Wis.	Sturgeon Bay Canal, Wis.	7011
Green Bay, Wis.	Green Bay, Wis.	Sturgeon Bay Canal, Wis.	7012
Green Bay, Wis. to Point Detour, Mich.	Green Bay, Wis.	Sturgeon Bay Canal, Wis.	7013

12.5.2 Regulation of Lake Winnebago

The Corps of Engineers operates the pool level of Lake Winnebago, insofar as possible, in the interests of navigation, water power, municipal water supply, sanitation, riparian landowners, fish and wildlife, recreation, and flood control. They maintain project depths on the lower Fox River during the navigation season. To provide these depths, enough water must flow from Lake Winnebago into the lower Fox River. Power interests on the lower Fox River want a uniform flow of water from Lake Winnebago for as long as possible. This requires impounding water in Lake Winnebago near the upper limits of regulation, so that water can be released as required. Any excess waters, within elevation limitations established by law and not required for navigation, are available for private interests to produce power. These private power rights antedate the Federal government's acquisition of the navigation project. The limits of regulation for Lake Winnebago under existing laws, orders, rules, and permits are from 21¼ inches above the crest of Menasha Dam down to the crest during the navigation season, plus an additional 18 inches below the crest in winter. The Wisconsin Conservation Department requests that the level of Lake Winnebago be at the crest of the Menasha Dam by April 1 of each year for fishery resources. There is a need to review the regulation of Lake Winnebago as part of the development of a water resources management plan for the Fox-Wolf River basin.

12.5.3 Upper Fox River

The upper Fox River project, authorized by the Rivers and Harbors Act of July 7, 1870, and subsequent acts, extended approximately 100 miles from the junction of the Fox and Wolf Rivers in Lake Butte des Morts to the junction of the Portage Canal with the Wisconsin River at Portage, Wisconsin. The project provided for a channel six feet deep, except between Montello and Portage where the channel depth was four feet. It included nine locks, seven dams, six cut-off sections, and an artificial canal two and one-fourth miles long at Portage, which connects the upper Fox River and the Wisconsin River.[7]

With the decline of commercial navigation on the upper Fox River from 1918 to 1928 and cessation in 1938, maintenance of this project by the United States would have been uneconomical. Subsequently, the Wisconsin Conservation Commission requested permission to develop the area for conservation and recreation. Section 108 of P.L. 500, 85th Congress, approved July 3, 1958, authorized transfer of all upper Fox River project facilities. The Wisconsin Conservation Commission ratified this on August 17, 1962.

12.5.4 Diversion Scheme for Wisconsin River to Fox River at Portage, Wisconsin

Long-range basin needs for the Fox River include pollution abatement and low flow regulation. The report "Study of Comprehensive

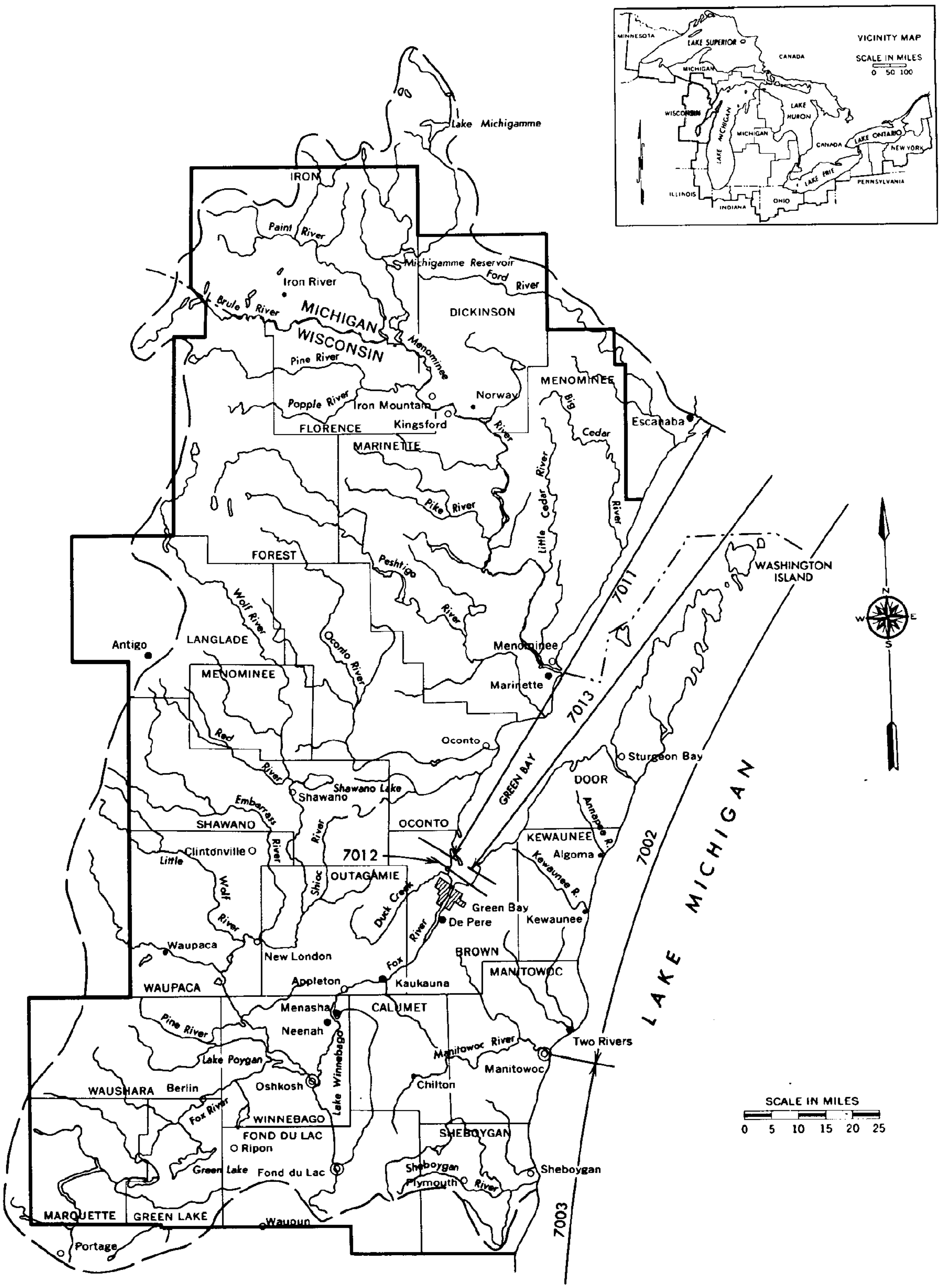


FIGURE 11–48 Planning Subarea 2.1

Scope", published by the Wisconsin State Planning Board in May 1938[51] proposed a scheme for interbasin diversion and recommended a 1,500 cfs diversion to aid Fox River water quality. Providing such an amount would require additional storage capacity on the Wisconsin River above Portage, Wisconsin, and possibly on the upper Fox River. The upper Fox River project could be modified to provide the means of discharging the diversion.

The fall in the upper Fox River is 30.5 feet from the former Fort Winnebago locksite to Lake Butte des Morts. At low flow, the Wisconsin River is 6.5 feet above the Fox, and 11.5 feet at maximum flood stage. The original Portage Canal was two and one-fourth miles long and 75 feet wide. The upper Fox River is 70 to 300 feet wide at low stages and flows through extensive low, marshy areas up to five miles wide. It contributes 27 percent of the total inflow to Lake Winnebago. Operation of the upper Fox River locks stopped in 1951. There are haulovers at six locations for recreational boats.

12.6 Planning Subarea 2.2

Planning Subarea 2.2 consists of the Chicago-Milwaukee complex drainage areas (Figure 11–49).

12.6.1 General

Ultimate storm water level data for the planning subarea were computed utilizing data from Table 11–49.

Serious beach and shore erosion problems exist in a major part of the shoreline of Planning Subarea 2.2, particularly during periods of abnormally high levels on Lake Michigan. During such periods, recreational and protective beaches which front the uplands along much of the shoreline have been drowned or eroded. The southwestern shore of the Lake is generally composed of fine sand. Severe onshore winds and storms move large amounts of it. The entire shorelands from Port Washington, Wisconsin, to Evanston, Illinois, consist of bluffs subject to severe erosion except where structures protect them.

12.6.2 Diversion from Lake Michigan at Chicago

Water from Lake Michigan and its drainage basin is diverted at Lockport, Illinois into the Des Plaines River, a tributary of the Illinois River and a part of the Mississippi River drainage basin. The City of Chicago and other cities in the Metropolitan Sanitary District pump approximately 1,700 cfs from Lake Michigan for domestic and industrial purposes. After use, most of this water is discharged into the waterways at sewage treatment plants and flows into the Mississippi River basin. In addition, surface runoff that originally flowed into Lake Michigan and water diverted directly from Lake Michigan, an estimated total of 1,500 cfs, flow through the Chicago area waterways into the Mississippi River basin.

The natural divide separating the Great Lakes drainage basin from the Mississippi River drainage basin passes 10 miles west of the Lake Michigan shoreline at Chicago. When the Sanitary and Ship Canal was constructed from Chicago to Lockport, it breached the divide near Summit where the divide was 10 feet above the level of Lake Michigan at LWD. Figure 11–50 illustrates the channel and river systems of the Chicago diversion.

Reversing the flow of the Chicago and Calumet Rivers and intercepting certain drainage areas along the shore of Lake Michigan at Chicago has eliminated 800 square miles from the Lake Michigan watershed. Locks and controlling works have closed the Chicago and Calumet Rivers to Lake Michigan. The Calumet River between O'Brien Lock and Lake Michigan flows either lakeward or toward Lockport depending on lake and canal stage and storm runoff. At Wilmette Harbor, a pumping station diverts lake water to the North Shore Channel. A sluice gate at this point is used for emergency storm water releases from the channel to the Lake.

On the western side of the divide is the Des Plaines River, which rises in southeastern Wisconsin and flows parallel to and 12 miles west of Lake Michigan's lakeshore. At a point near Summit, Illinois, it turns southwestward 273 miles and empties into the Mississippi River at Grafton, Illinois. Prior to 1848, in periods of extreme high water the Des Plaines River would overflow the divide and discharge floodwater to the Chicago River into Lake Michigan.

Between Lake Michigan and the divide lie the Chicago River and its two branches, the North Branch which flows south, and the South Branch, which, before the Sanitary and Ship Canal was constructed, flowed north.

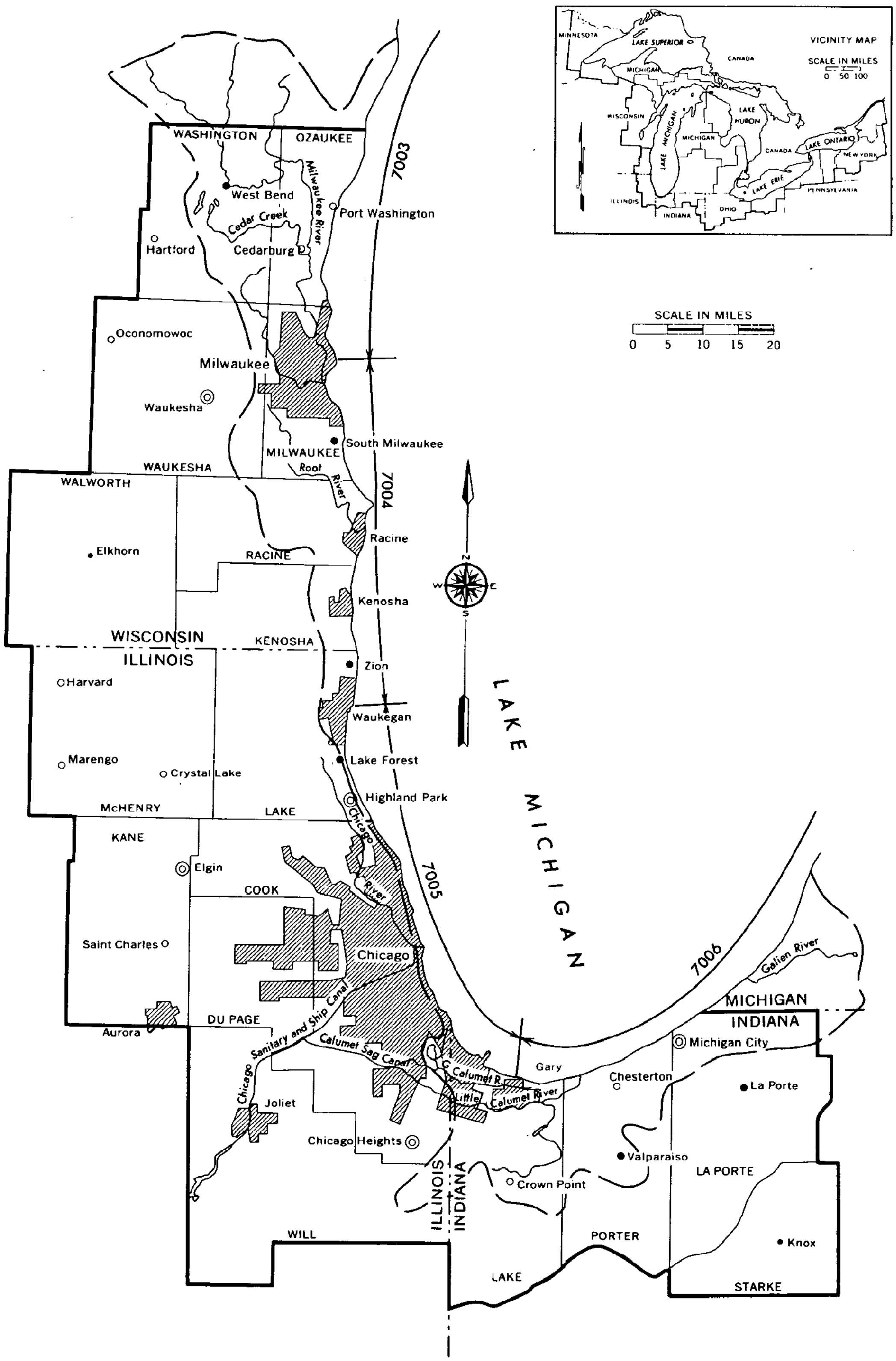


FIGURE 11-49 Planning Subarea 2.2

TABLE 11-49 Data Stations, Planning Subarea 2.2

Reach of Shore	Weather Station	Water Level Station	Reach No.
Manitowoc, Wis. to Milwaukee, Wis.	Milwaukee, Wis.	Milwaukee, Wis.	7003
Milwaukee, Wis. to Waukegan, Ill.	Milwaukee, Wis.	Milwaukee, Wis.	7004
Waukegan, Ill. to Gary Harbor, Ind.	Chicago Midway, Ill.	Calumet Harbor, Ill.	7005
Gary Harbor, Ind. to South Haven, Mich.	Chicago Midway, Ill.	Calumet Harbor, Ill.	7006

Approximately 1.6 miles from the controlling works situated off the mouth of the Chicago River, the two branches unite to form the main channel of the Chicago River which flowed into Lake Michigan before the Sanitary and Ship Canal was constructed.

Prior to 1900 the flow of the Chicago River was reversed so that it flowed landward, away from Lake Michigan, into the Sanitary and Ship Canal, which begins at the West Fork of the South Branch of the Chicago River. Flowing southwestward, away from Lake Michigan, the Sanitary and Ship Canal cuts through the divide that separates the Great Lakes Basin from the Mississippi River basin and enters the Des Plaines River drainage area. The canal parallels the Des Plaines River and ultimately joins that river near Lockport, Illinois, 31 miles downstream from the junction of the South Branch and the Sanitary and Ship Canal.

A canal known as the North Shore Channel connects the North Branch of the Chicago River with Lake Michigan at Wilmette, Illinois, a suburb north of Chicago. This channel flows south 8.1 miles to join the North Branch of the Chicago River. Diversions from Lake Michigan and its drainage basin through the North Shore Channel flow into the Sanitary and Ship Canal via the North and South Branches of the Chicago River.

At the Wilmette intake of the North Shore Channel are a sluice gate (installed in what was once a lock) and a pumping station designed to permit lake water to be pumped into the channel. This structure normally prevents flow from the channel to the Lake.

At the mouth of the Chicago River, there are sluice gates and a lock which permit lake water to enter, and normally prevent river water from flowing into the Lake. The Chicago River has a normal water level of 0.6 foot below the LWD level of Lake Michigan. The amount of lockage water required depends on the number of lockages as well as the relative water levels of Lake Michigan, the Chicago River, and the Sanitary and Ship Canal at the time of each lockage. An estimated annual requirement of this lock is 45 cfs.

Since completion of the control works, several severe storms have produced enough runoff to require the gates in the locks at the mouth of the Chicago River to be opened for several hours to permit the North Shore Channel to flow into Lake Michigan. The flow was allowed to enter the Lake because the hydraulic capacity of the canals could not carry all of the storm runoff to the Lockport outlet.

The Little Calumet River and Grand Calumet River rise in the State of Indiana. Part of the flow of the Little Calumet River (that part of the stream lying east of Burns Ditch and Burns Waterway) enters Lake Michigan in Indiana through Burns Waterway, and a part flows into Illinois.

Water diverted from Lake Michigan enters the Sanitary District's canals from three separate sources: directly from Lake Michigan through the locks and control works at the mouth of the Chicago River and at Wilmette; the Calumet River and the Little Calumet River; and the control works in the Calumet River.

Part of the runoff from the drainage basins of the Chicago River and Calumet River systems, which flowed into Lake Michigan before the canals were constructed, now flows directly into the canals or their tributaries, or is diverted into the canals or their tributaries

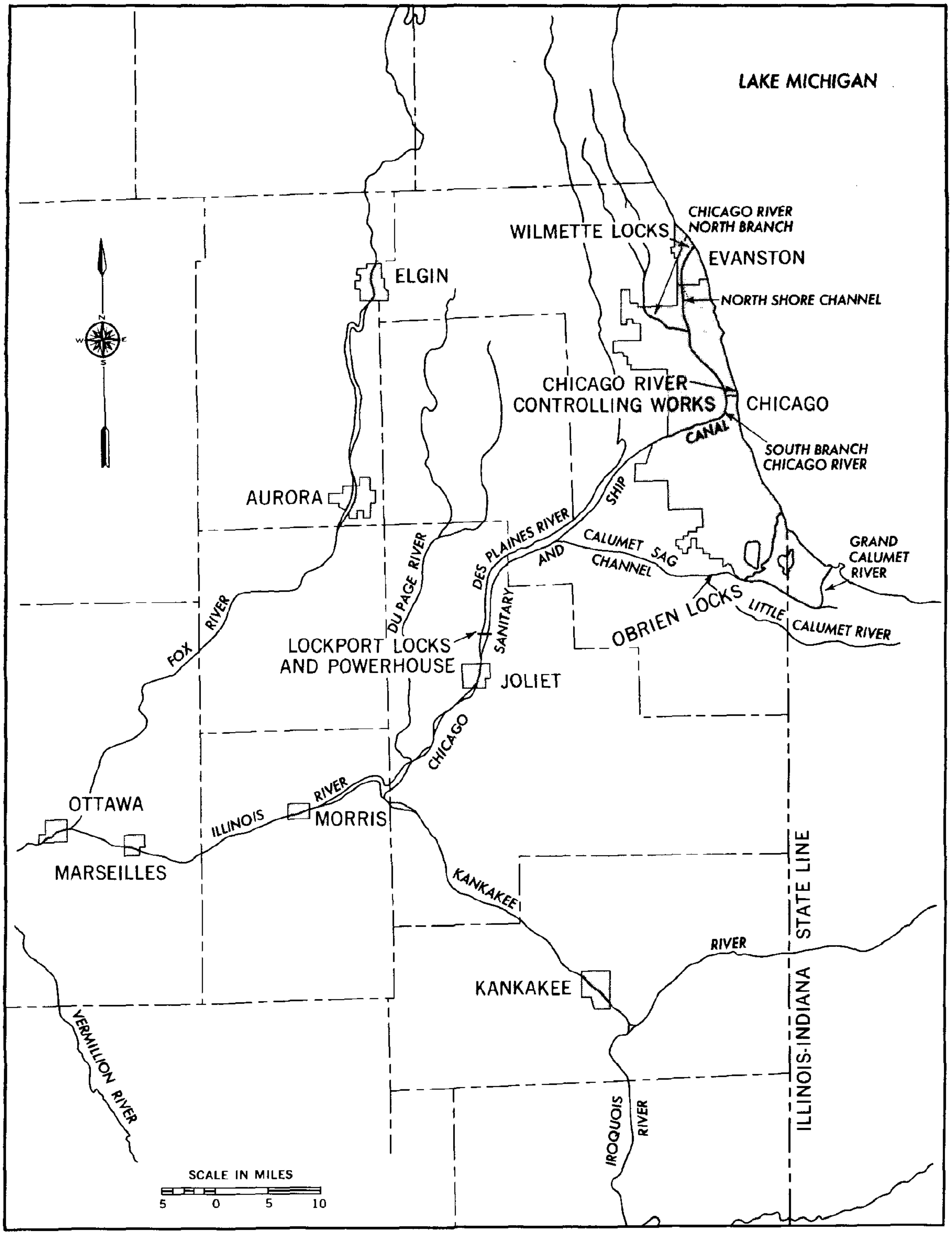


FIGURE 11-50 Channel and River Systems—Chicago Diversion

through the Sanitary District sewers, interceptors, and treatment plant systems. Water withdrawn from Lake Michigan through the intake cribs of the City of Chicago for domestic, industrial, and other purposes is discharged after use into the Sanitary District's canals in the form of sewage effluent and spillage from the interceptors. Water from the cities in the Sanitary District not served with water by the City of Chicago, some of which is also taken from Lake Michigan and its drainage basin, is discharged into the Sanitary District's canals after use.

The 1930 Decree of the Supreme Court of the United States[29] limited the amount of diversion through the Chicago Drainage Canal, its auxiliary channels or otherwise, to an annual average of 1,500 cubic feet per second in addition to domestic pumpage. The June 12, 1967 Decree of the Supreme Court of the United States,[48] which became effective on March 1, 1970, enjoins the State of Illinois and its municipalities, political subdivisions, agencies, and instrumentalities from diverting any waters from Lake Michigan or its watershed into the Illinois Waterway in excess of an average of 3,200 cubic feet per second. When necessary, a five-year accounting period is allowed for achieving the average of 3,200 cubic feet per second. The total is not allowed to exceed 110 percent in any annual accounting period.

The State of Illinois is not now in compliance with the provisions of the Decree although substantial progress has been made. A series of six public hearings has been held throughout northeastern Illinois to receive evidence from individuals and agencies that wish to use water from Lake Michigan, to set forth background information.

Preliminary information supplied at the public hearings has been analyzed. The State of Illinois will probably not request an increase in the allocation of Lake Michigan water until after the year 1985. With proper housekeeping measures Illinois will be able to make sufficient allocation to satisfy the identified needs for the northeastern portion of the State up to that date.

The Illinois Division of Waterways has initiated work on the Lake Michigan diversion program. This agency is planning an initial allocation order concerning waters from Lake Michigan, based upon flow rates identified at the public hearings. It is expected that the order will be acceptable to all parties, and no litigation is anticipated. Part of that order will be an indication of the anticipated change in allocation during the 20-year period following the date of the order. Certain agencies, such as the Metropolitan Sanitary District and the City of Chicago, are to reduce the required diversion by higher quality waste treatment and greater control over leak problems within their distribution systems.

12.6.3 Chicago Metropolitan Area

Flooding has been a severe problem since the closing of natural outlets at Chicago Harbor in 1938 and O'Brien Lock in 1965. These tributaries ordinarily drain into the Mississippi River basin through the Lockport outlet. However, severe storms produce enough runoff to require control gates to be opened at the mouth of the Chicago River, at O'Brien Lock, and control works on the Calumet River or at Willmette, Illinois, on the North Shore Channel, allowing excess flows to enter Lake Michigan. Prior to 1954 no problems of this nature occurred. Since that time, because of urbanization, increased runoff in severe storms has necessitated the release of flood waters into Lake Michigan. Flows are permitted to enter the Lake in order to avoid serious flood damage in the area. When the releases occur in summer, beaches must be closed for several days because the releases degrade Lake Michigan's water. Several interested agencies, including the Metropolitan Sanitary District, the City of Chicago, and the State of Illinois, have suggested ways of alleviating flood problems. Plans considered include some or all rivers and canals in the Chicago metropolitan area. Preliminary cost estimates and feasibility studies are being made.

The Metropolitan Sanitary District of Greater Chicago has suggested a series of detention reservoirs which would hold storm water in many small basins throughout the area from the time of an intense rainfall until the water could be released without causing damage. Larger reservoirs on some streams in the area other than the Chicago River have also been considered. The Metropolitan Sanitary District of Greater Chicago considers this system most applicable to suburban areas with separate sewers.

The Sanitary District has also suggested storing floodwaters in large underground tunnels. During storm periods, water would enter these tunnels through dropshafts, be conveyed to large underground storage areas and be pumped out after the storm. Moderate pumping rates would allow existing sewage treatment plants to treat polluted storm water. The Metropolitan Sanitary District of Greater Chicago considers this system most applicable to the combined-sewer inner areas of Chicago.

The City of Chicago has suggested a similar tunnel system, but it would have less underground storage and a large conveyance capacity to the Lockport outlet of the Illinois Waterway. This scheme is also considered most applicable to the combined-sewer area where subsequent treatment of polluted storm water is a major objective. The State of Illinois has proposed a plan for flood control and improvement of drainage in the Chicago area by modification of the Sanitary and Ship Canal and the Calumet-Sag Channel. Suggested structural changes would allow the normal water surface in the Canal and the Channel to be lowered 10 feet. The Canal would be widened. This improved system would provide greater discharge capacity at lower stages, greatly reducing direct flooding and indirect flooding due to sewer-outlet submergence. The deepened and widened canal would also provide a major navigation improvement for commercial barge tows.

A technical advisory committee has been formed for developing one coordinated plan. The Northeastern Illinois Planning Commission has already endorsed the concept of both tunnel plans in its wastewater plan for the combined-sewer areas. The technical advisory committee recommended that the City and Sanitary District start detailed design on a portion of the tunnel system.

12.6.4 Milwaukee River Basin Flood Control Proposal

A principal feature of this plan for water resource development and flood control in the Milwaukee River basin includes a proposed diversion channel north of Milwaukee to divert flood flows from the Milwaukee River to Lake Michigan. The proposal provides diverting the Milwaukee River to Lake Michigan by a channel or channels near Saukville and Thiensville, Wisconsin. Constructing such a project would not affect the levels of Lake Michigan.

12.6.5 Fox and Des Plaines Rivers Proposal

Some interests have suggested a plan to help alleviate flood damages on both the Fox and Des Plaines Rivers (Mississippi River basin) by impounding floodwaters in a common reservoir. The suggested reservoir would occupy a valley in lower Wisconsin from a dam site on the Des Plaines River directly west of Kenosha to a dam on the Root River near the northern boundary of both rivers. This reservoir would connect the Fox River system at the north end by a waterway entering the Fox River just below the present dam at Wilmot, Wisconsin. The reservoir would also connect to Lake Michigan by a subsurface conduit at the north end. The reservoir would store storm water from the rivers and also be a pumped-storage reservoir. No one has determined the feasibility of such a plan or shown much interest in it.

12.6.6 Little Calumet River Proposal

The Little Calumet River floods as a result of heavy runoff on its tributaries, principally Hart Ditch and Thorn Creek. Under existing conditions the flows that originate in Indiana discharge into Lake Michigan. All flows in the Illinois part of the basin discharge into the Calumet-Sag Channel and eventually reach the Mississippi River via the Illinois River. Hart Ditch flows can outlet either to Lake Michigan or to the Calumet-Sag Channel depending on stream levels, because of the high point in the riverbed just east of Hart Ditch. From this point the streambed of the Little Calumet River slopes eastward toward Lake Michigan and westward to the Calumet-Sag Channel. When flood levels are higher than the streambed at the high point, water from Hart Ditch can flow both east and west. The plan for the Little Calumet River will maintain the normal drainage pattern of dry weather flow but will divert all Hart Ditch flood flow eastward to Lake Michigan. Hart Ditch flow is counted in the 3,200 cfs diversion with the present average flow of 56.6 cfs. Proposed construction of the dam and 10 cfs pumping station will reduce this amount (Hart Ditch flow into the Illinois Waterway), enabling more strategic diversion elsewhere in the Metropolitan Sanitary District of Greater Chicago system. This would not affect Lake Michigan levels because when such an improvement occurs, the resulting amount of water would probably be reallocated in the northeastern Illinois metropolitan area. In Indiana, storm water presently flows into Lake Michigan by natural drainage. Storm water flows from Illinois are not usually al-

TABLE 11-50 Data Stations, Planning Subarea 2.3

Reach of Shore	Weather Station	Water Level Station	Reach No.
Gary Harbor, Ind. to South Haven, Mich.	Chicago Midway, Ill.	Calumet Harbor, Ill.	7006
South Haven, Mich. to Big Sable Point, Mich.	Muskegon, Mich.	Ludington, Mich.	7007

TABLE 11-51 Data Stations, Planning Subarea 2.4

Reach of Shore	Weather Station	Water Level Station	Reach No.
South Haven, Mich. to Big Sable Pt., Mich.	Muskegon, Mich.	Ludington, Mich.	7007
Big Sable Pt., Mich. to Empire, Mich.	Traverse City Mich.	Ludington, Mich.	7008
Empire, Mich. to Straits of Mackinac, Mich.	Pellston, Mich.	Mackinaw City, Mich.	7009
Straits of Mackinac, Mich. to Point Detour, Mich.	Pellston, Mich.	Mackinaw City, Mich.	7001
Point Detour, Mich. to Escanaba, Mich.	Green Bay, Wis.	Sturgeon Bay Canal, Wis.	7010

lowed to flow into Lake Michigan. The O'Brien Lock in the Calumet River, the Chicago Harbor Lock, and the control structure at Wilmette Harbor prevent this from occurring until river-canal stages exceed five feet above lake level (+5 Chicago City Datum). However, during severe flood conditions when stages exceed +3.5 ft. CCD at Chicago Harbor Lock and O'Brien Lock and +5 ft. CCD at Wilmette, these outlets are opened to forestall extreme flood damages in the Chicago metropolitan area as noted in the description of diversion from Lake Michigan at Chicago.

12.7 Planning Subarea 2.3

Planning Subarea 2.3 consists of the following drainage areas: St. Joseph River, Black River Complex, Kalamazoo River, Grand River, and Ottawa Complex (Figure 11-51).

12.7.1 General

Ultimate storm water level data for the planning subarea were computed utilizing data from Table 11-50. Generally the Lake Michigan shoreline in this planning subarea consists of an almost continuous sand beach bordered intermittently by bluffs and sand dunes. Along this segment of shoreline, especially during times of high lake levels, erosion of beach and undercutting of the bluff is continuous.

Several localities of the planning subarea have problems related to filling-in of the flood plain without necessarily encroaching into the riverbed itself. The Michigan Department of Natural Resources is presently working with local interests to restrict further filling in these several localities and to dike existing fills to prevent materials from getting into the adjacent river and lake.

12.8 Planning Subarea 2.4

Planning Subarea 2.4 consists of the following drainage areas: Manistee River, Traverse Complex, Les Cheneaux Complex, Seul Choix-Groscap Complex, Manistique River, and Escanaba River (Figure 11-52).

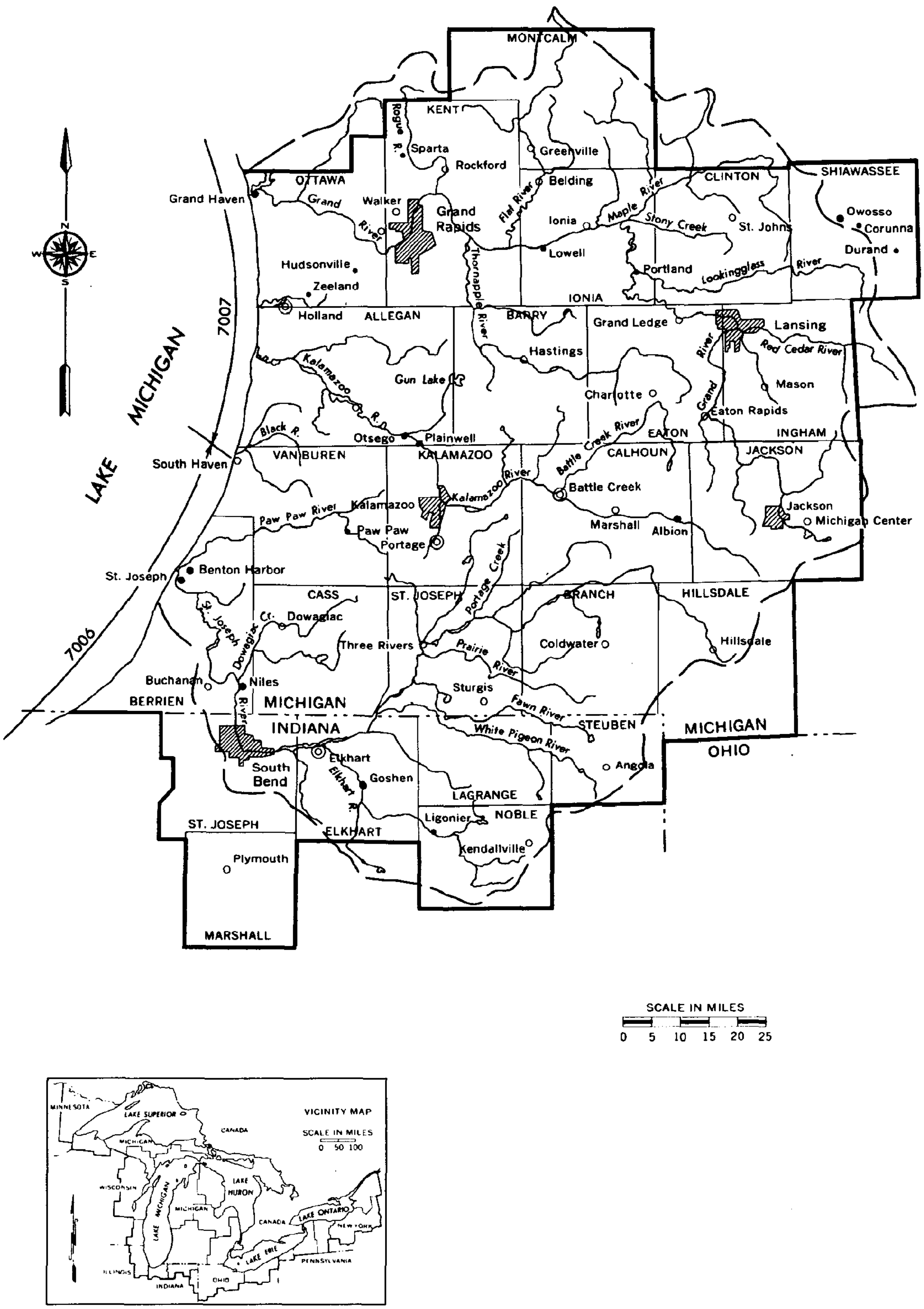


FIGURE 11-51 Planning Subarea 2.3

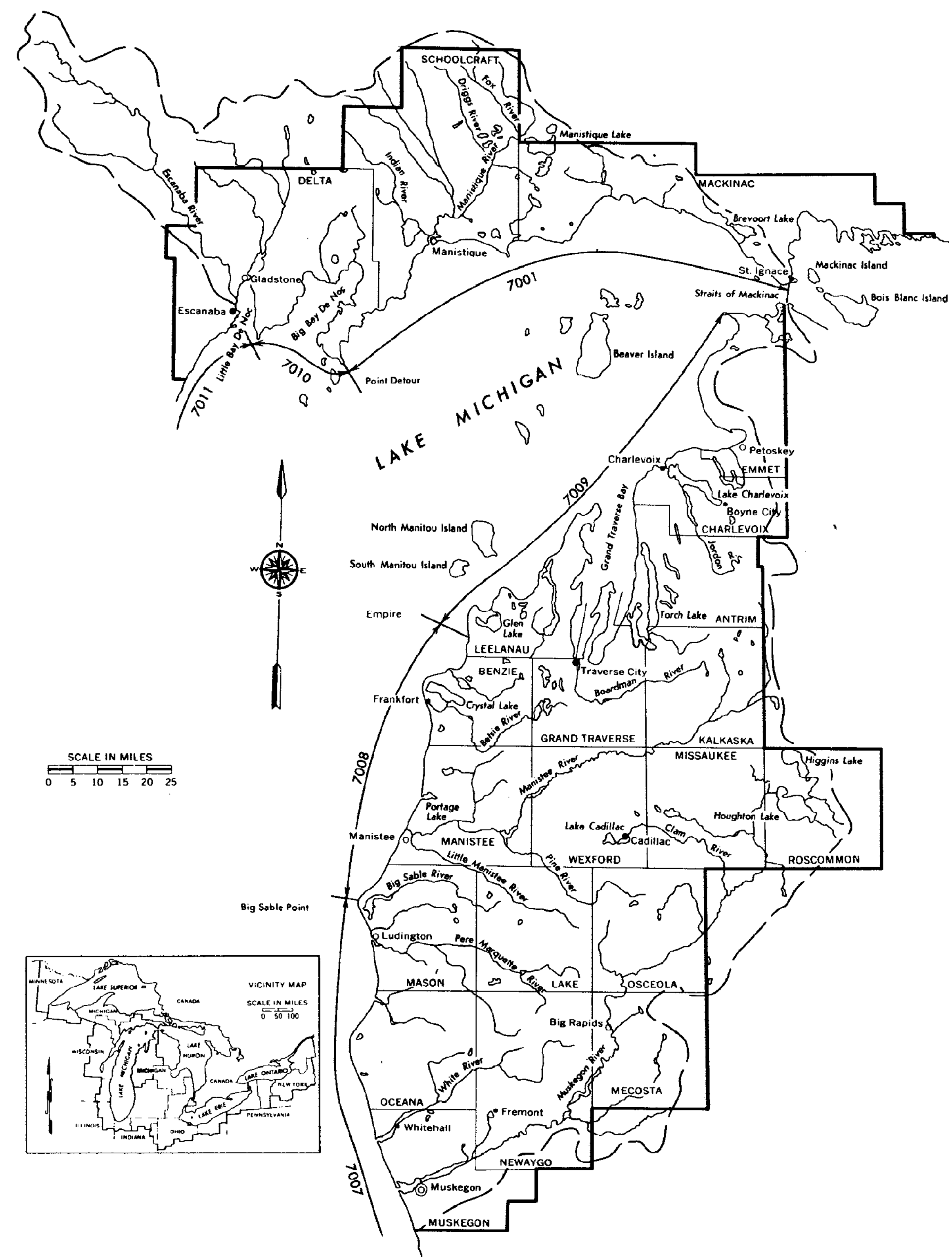


FIGURE 11-52 Planning Subarea 2.4

12.8.1 General

Ultimate storm water level data for the planning subarea were computed utilizing data from the locations listed in Table 11–51.

From the Straits of Mackinac to Grand Traverse Bay the shoreline is characterized by narrow cobble beaches, backed in some stretches by high bluffs with only minor erosion. The shoreline from the tip of Leelanau County south to Muskegon consists of sandy beaches backed with dunes or bluffs severely eroded by high lake levels.

Natural rock points protruding into the Lake generally protect this planning subarea's shorelines along the Upper Peninsula, except for several sandy beach areas.

Filling in of the flood plain proper is also a problem. It is more acute in the Muskegon River basin than elsewhere in this planning subarea, because of the close proximity to a large metropolitan-industrial area. The Michigan Department of Natural Resources controls filling activities by virtue of its administration of Act 291, P.A. 1965, as amended. Filling actually started before the turn of the century when lumbering interests were very active in this river basin, and most of the sawmills and boom areas were on the lower reaches of the Muskegon River.

Section 13

LAKE HURON PROBLEMS AND NEEDS

13.1 General

This section presents information, problems, and needs related to levels and flows of Plan Area 3 (Lake Huron), which consists of two planning subareas (Figure 11–53).

13.2 Fluctuations of Lake Huron

The average elevation of the lake surface varies irregularly from year to year. Each year, the surface is subject to a consistent seasonal rise and fall, the lowest levels prevailing in winter, the highest in summer. In the 110 years from 1860 to 1969, the difference between the highest (581.94) and the lowest (575.35) monthly mean stages of the whole period has been 6.59 feet (Harbor Beach, Michigan). The greatest annual fluctuation as shown by the highest and the lowest monthly means of any year was 2.23 feet, and the least annual fluctuation was 0.36 foot.

13.2.1 Compensation Works on Lakes Michigan-Huron Natural Outlet

As a result of the dredging of the 25-foot and 27-foot navigational projects in the St. Clair and Detroit Rivers, increased channel cross-sectional areas have caused greater outflows for a given Lakes Michigan-Huron level. The increased channel capacity lowered the water levels of Lakes Michigan-Huron approximately seven inches.

The United States has developed plans to compensate for this lowering by structural means to be built in the St. Clair River. Canada in 1962 agreed in principle to compensation, but no specific plan was agreed upon. This project has been delayed pending the results of the IJC Study, discussed in more detail in Subsection 14.3.

13.3 Planning Subarea 3.1

Planning Subarea 3.1 consists of the following drainage areas: Cheboygan River, Presque Isle Complex, Thunder Bay, Alcona Complex, Au Sable River, and the Rifle-Au Gres Complex (Figure 11–54).

13.3.1 General

Ultimate storm water level data for the Lake Huron shore of Planning Subarea 3.1 were computed with data from Table 11–52. Certain segments of shoreline north of Tawas Point on Lake Huron have experienced considerable damage to docks, beaches, and residences, and threats to some cottage development, particularly during high lake level periods. Because of the physical nature of the beaches on Lake Huron in this planning subarea, characterized by gradual slope and extensive stretches of sand and rock shoreline, erosion is minimal compared to other portions of Lake Huron.

13.3.2 Shoreline Filling

Problems concerning filling have occurred along the shore of Lake Huron within larger communities such as Cheboygan, Rogers City, Alpena, Tawas City, and East Tawas City. The largest fill in the State was created years ago and is now part of the U.S. Steel Corporation's Port Calcite operation near Rogers City. This fill encompasses 175 acres of Lake Huron bottomland, conveyed to the company under provisions of the Great Lakes Submerged Lands Act. Many of the other fills in this area were made in connection with previous lumbering activities or the development of large cement-making facilities and quarrying activities. Provisions of Act 247, Public Acts of 1955, as amended, now control Lake Huron filling. At the present time, filling and dredging activities within the inland rivers are also under jurisdiction of the Michigan Department of Natural Resources by virtue of its administration of Act 291, Public Acts of 1965, as amended.

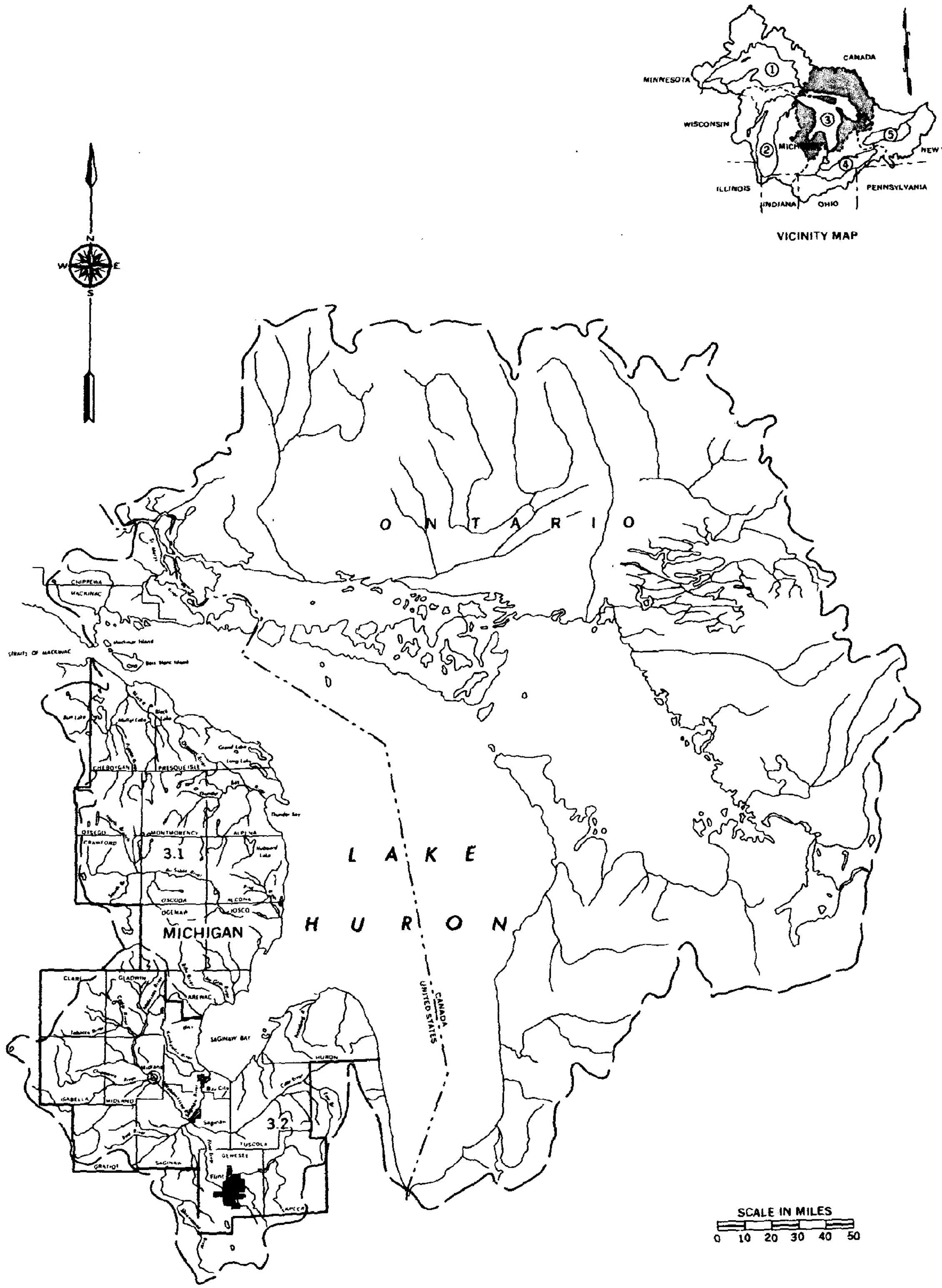


FIGURE 11-53 Plan Area 3

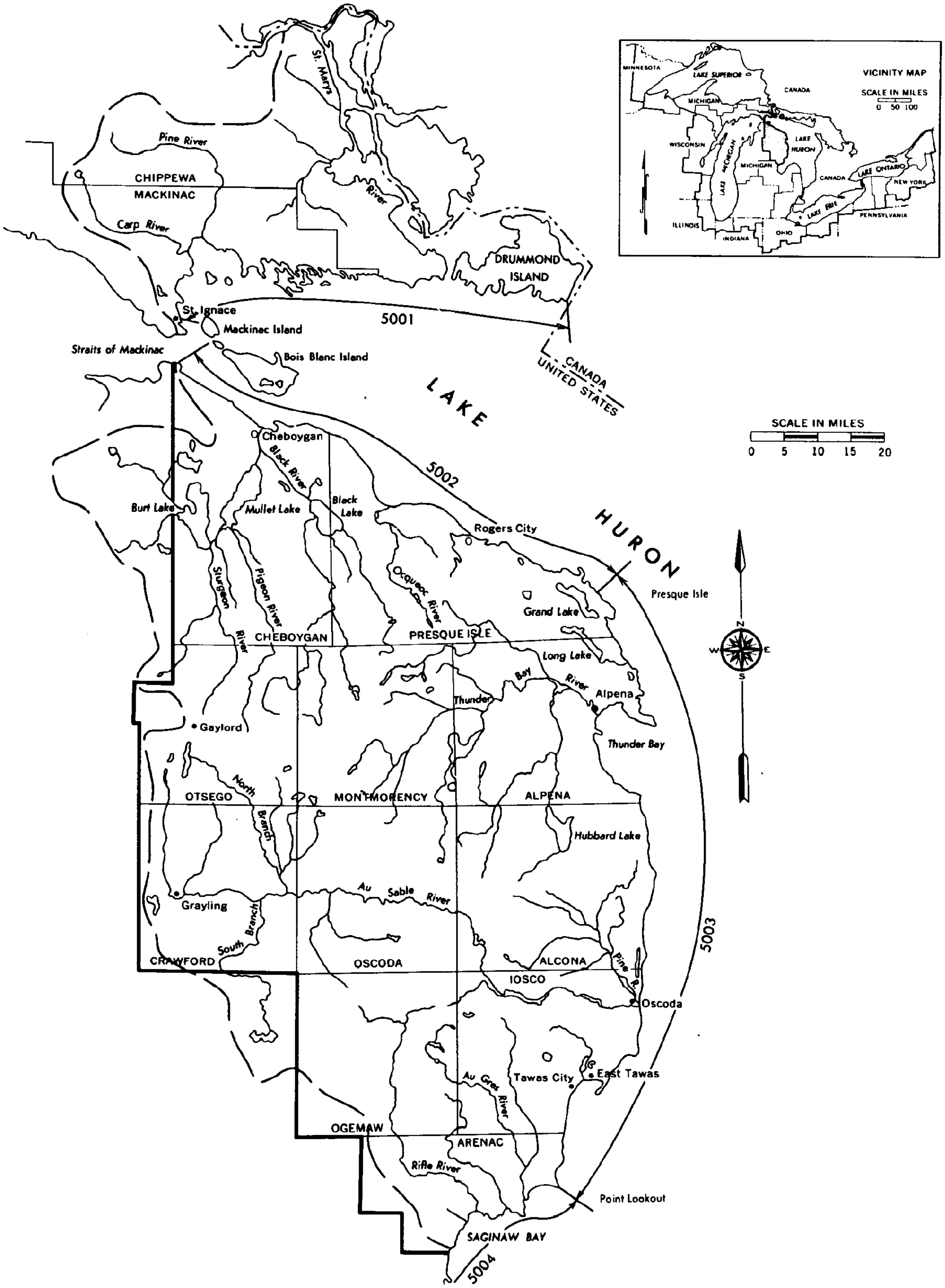


FIGURE 11–54 Planning Subarea 3.1

TABLE 11-52 Data Stations, Planning Subarea 3.1

Reach of Shore	Weather Station	Water Level Station	Reach No.
International Boundary to Straits of Mackinac, Mich.	Pellston, Mich.	Mackinaw City, Mich.	5001
Straits of Mackinac, Mich. to Presque Isle, Mich.	Pellston, Mich.	Mackinaw City, Mich.	5002
Presque Isle, Mich. to Point Lookout, Mich.	Alpena, Mich.	Harbor Beach, Mich.	5003
Point Lookout, Mich. to Essexville, Mich.	Saginaw, Mich.	Essexville, Mich.	5004

TABLE 11-53 Data Stations, Planning Subarea 3.2

Reach of Shore	Weather Station	Water Level Station	Reach No.
Pt. Lookout, Mich. to Essexville, Mich.	Saginaw, Mich.	Essexville, Mich.	5004
Essexville, Mich. to Pte. Aux Barques, Mich.	Saginaw, Mich.	Essexville, Mich.	5005
Pte. Aux Barques, Mich. to Port Huron, Mich.	Saginaw, Mich.	Harbor Beach, Mich.	5006

13.4 Planning Subarea 3.2

Planning Subarea 3.2 consists of the following drainage areas: Kawkawlin Complex, Saginaw River, and Thumb Complex (Figure 11-55).

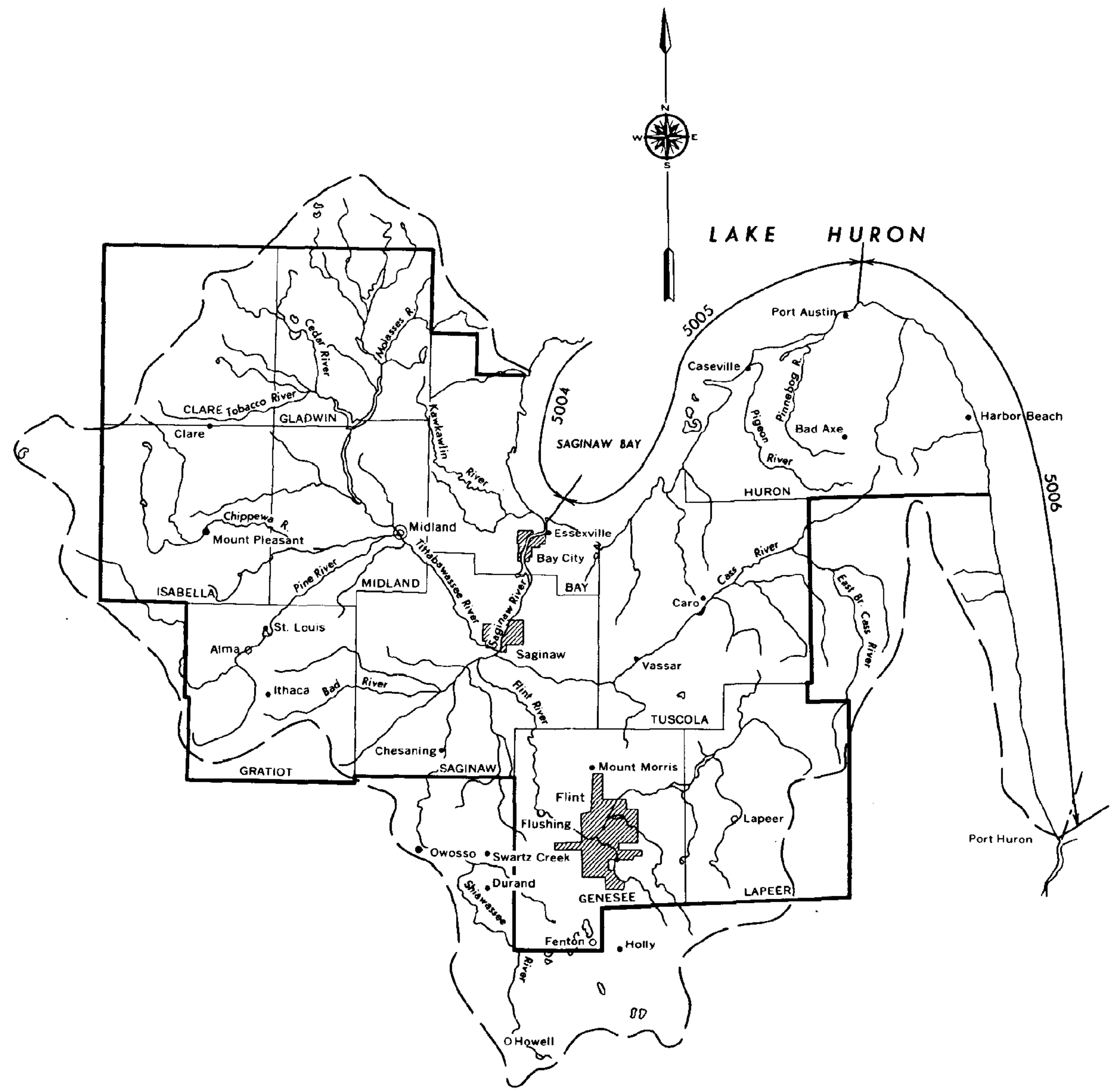
13.4.1 General

Ultimate storm water level data for the Lake Huron shore of Planning Subarea 3.2 were computed utilizing data from the areas listed in Table 11-53.

Locally, so-called wind tides on the Saginaw River demonstrate the most prominent occurrence of the seiche or surge phenomenon on Lake Huron. They exceed six-foot variance at Green Point (Saginaw River formed by the confluence of the Tittabawassee and Shiawassee Rivers at Green Point) at the upstream limits of the City of Saginaw. The slope of the Saginaw River between Green Point and Saginaw Bay is usually flat except under dry-weather flow conditions, when the level of Lake Huron largely controls its elevation. In small areas used for truck farming along Saginaw Bay, tile drainage systems are operated so that when wind tides on Saginaw Bay create reverse flows in the main drains, the water flows into laterals and subirrigates the tile field. The tile fields have been designed to utilize this method of water supply recharging during the dry season. Pump irrigation systems also use the water from the drains. A similar technique is applied in maintaining wildlife marsh habitat in this planning subarea.

Serious beach and shore erosion problems exist in segments of the shoreline of the planning subarea, particularly from Pointe Aux Barques to Port Huron. The shore of the Lake varies from rocky to clay bluffs with sections of fine sand. The sandy portions are most mobile during severe onshore winds and storms, and in places some groins have been constructed to protect beaches. Because the Saginaw Bay beaches have gradual slopes and extensive stretches of marsh vegetation, erosion is minimized in comparison to other portions of Lake Huron.

Because of the small gradient of the beaches and marshes (particularly along Saginaw



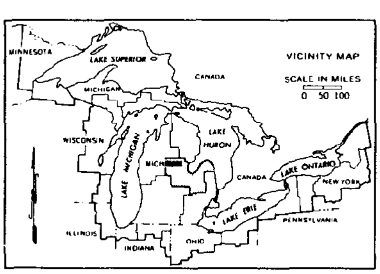


FIGURE 11-55 Planning Subarea 3.2

Bay's shoreline), one of the main problems in this planning subarea is that low lake levels have a significant effect on recreational navigation activities and fish and wildlife habitat. Acres of shallow water habitat are lost physically.

13.4.2 Shoreline Filling

Some problems concerning filling-in of the flood plain have occurred within the Saginaw River system, which includes the City of Saginaw and Bay City. The problem is more acute in the lower Saginaw River than elsewhere in the area, primarily because of its proximity to a large metropolitan-industrial area where large quantities of earth and rubble are readily available. Filling actually started before the turn of the century when lumbering interests were very active in this river basin. Most of the sawmills and boom areas were on the lower reaches of the river. The Michigan Department of Natural Resources now controls such fills.

Section 14

LAKE ERIE AND LAKE ST. CLAIR PROBLEMS AND NEEDS

14.1 General

This section presents information, problems, and needs related to levels and flows of Plan Area 4 (Lake Erie and Lake St. Clair), which consists of four planning subareas. Figure 11–56 is a map of this area.

14.2 Fluctuations of Lakes Erie and St. Clair

The average or normal elevation of Lake Erie water level varies irregularly from year to year. During the course of each year, the surface is subject to a consistent seasonal rise and fall, the lowest levels prevailing in winter, the highest in summer. In the 110 years from 1860 to 1969, the difference between the highest, 572.76 feet IGLD (1955), and the lowest, 567.49 feet, monthly mean stages at Cleveland, Ohio, for the whole period has been 5.27 feet. The greatest annual fluctuation as shown by the highest and lowest monthly means of any year was 2.75 feet, and the least annual fluctuation was 0.87 foot.

On Lake St. Clair the range of water levels has fluctuated during a 72-year period (1898 to 1969) between 575.70 feet and 569.86 feet monthly mean elevations, a difference of 5.84 feet. The greatest annual fluctuation was 3.32 feet and the least annual fluctuation was 0.88 foot.

In addition to the annual fluctuations, there are also storm-caused oscillations of irregular amount and duration. Some, lasting a few minutes to a few hours, result from squall conditions. These fluctuations are produced by a combination of wind and barometric pressure changes that accompany the squalls. At other times the lake level is affected for somewhat longer periods. Strong winds of sustained speed and direction drive the surface water forward in greater volume than that carried by the lower return currents. This raises the elevation on the lee shore and lowers it on the weather shore. This type of fluctuation has a pronounced effect on Lake Erie because it is the shallowest of the Great Lakes, and affords the least opportunity for the impelled upper water to return through reverse currents below the depth disturbed by storms. This result is materially augmented in bays and at the Lake's extremities, where converging shores impel water in a restricted space, especially where a gradually sloping inshore bottom reduces the depth and checks the reverse flow via lower currents.

At the eastern end of Lake Erie westerly winds pile up the water in Buffalo Harbor and increase the depth in the Niagara River, while easterly winds drive the water out of Buffalo Harbor and lessen the flow and depth of the Niagara River. The winds produce exactly the reverse effect at the western end of the Lake, their maximum effect occurring at Toledo, Ohio and at the mouth of the Detroit River.

Since 1900, the highest level recorded at Buffalo, New York, was on November 3, 1955, when 579.09 feet was reached, while the lowest recorded level was 564.17 feet on March 10, 1964. The extreme range of fluctuations during the total recorded period was 14.9 feet. The greatest range for any one year was 11.6 feet in 1927.

In extreme cases these wind set-ups have produced differences of more than 13 feet between lake levels at Buffalo, New York and Toledo, Ohio.

The storm of April 27, 1966 on the western shore of Lake Erie produced a record instantaneous lake stage of 7.1 feet (575.7 feet) at Toledo Harbor or 5.5 feet above the April 1966 monthly level of Lake Erie. Serious flooding and direct waves damaged the western shore of Lake Erie from Estral Beach, Michigan to Toledo, Ohio, continuing easterly along the shoreline to Marblehead, Ohio. The post-flood damage survey by the Corps of Engineers, Detroit District, estimated shore property damage for the State of Michigan at $1,181,000 and $926,000 for the State of Ohio. The record minimum instantaneous low level of Toledo was 561.41 feet, on January 2, 1942. Raising or lowering the water level at the west end of

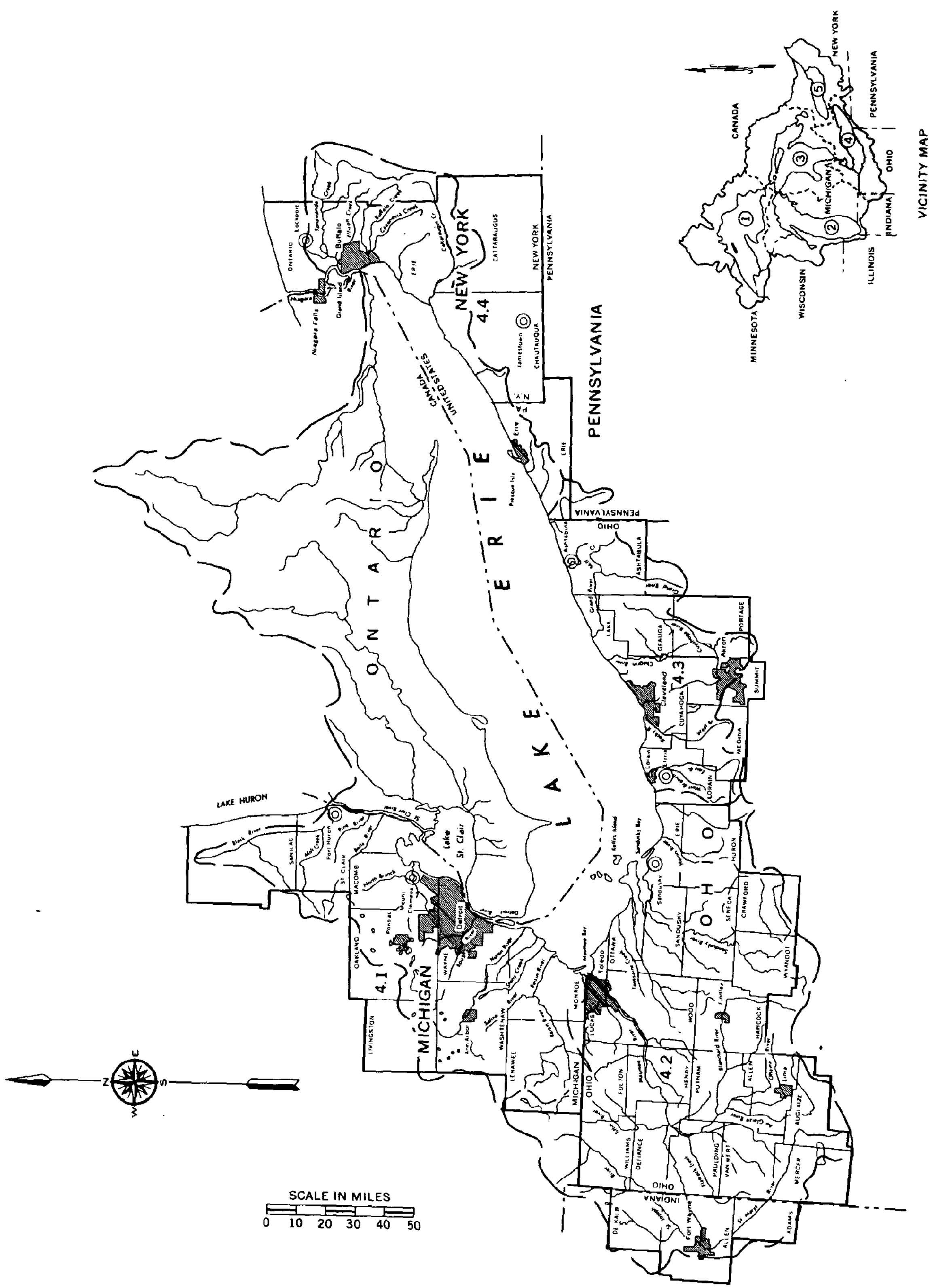


FIGURE 11–56 Plan Area 4

Lake Erie similarly affects the level of the lower Detroit River, with changes as much as six feet within eight hours.

14.2.1 Seiches

Wind is the primary cause of oscillations in Lake Erie. Because the Lake Erie basin is extremely shallow, the wind tilts its surface in a very short time, causing the water to be low at one end and high at the other.

Hunt,[17] Verber,[49] and others have described the seiches and oscillations in Lake Erie. The entire Lake Erie shoreline gets these brief fluctuations at various times. Variations in wind movement seem to start the various seiches.

14.2.2 Harbor Resonance

An 8.2-foot rise of lake levels has occurred over the period of record at Buffalo, with a substantially lower level resulting at the opposite end of the Lake at Toledo. During such an extreme rise of lake levels at Buffalo, by extrapolation the estimated rise would be 1.1 feet at Ashtabula and 2.0 feet at Conneaut. Cleveland, located in the nodal zone of the Lake, exhibits little fluctuation during such an occurrence. Knowledge of the magnitude and occurrence of brief fluctuations in the harbors and along the shoreline of Lake Erie is important for safe navigation.

14.2.3 Diked Areas for Disposal of Dredged Material

The Corps of Engineers harbor maintenance dredging program is using diked areas for disposal of dredged material in Buffalo and Cleveland. Lake level data are needed for designing and constructing the diked areas. Such information will continue to be necessary as the program continues and other harbors adopt this type of disposal of dredged material.

14.3 Planning Subarea 4.1

Planning Subarea 4.1 consists of the following drainage areas: Black River, St. Clair Complex, Clinton River, Rouge Complex, Huron River, Swan Creek Complex, and Raisin River (Figure 11-57).

14.3.1 General

Ultimate storm water level data for the Lake Erie shore of Planning Subarea 4.1 were computed using data from Table 11-54. Ultimate storm water level data have not been computed for Lake St. Clair.

Problems of shore use and erosion differ greatly through Planning Subarea 4.1. In Lake St. Clair one problem involves control of filling and occupation of bottomlands. From the mouth of the Detroit River to Toledo, the problem is one of erosion and inundation of the shoreline during high level periods and severe storms. This shoreline consists of low, easily eroded clay bank and swampy estuaries so that inundation from waves during high lake levels damages the shore. Beach erosion control in this area has consisted primarily of seawall construction, with some lesser amounts of diking and groin construction. A serious example is the shoreline at Lost Peninsula, Erie Township, Monroe County, Michigan, which has eroded 1,176 feet since 1835 (when the land was surveyed). Lost Peninsula is between the mouths of the Maumee and Ottawa Rivers and near the Ohio border.

One of the other problems in Planning Subarea 4.1 relates to the filling in of the flood plain without necessarily encroaching into the riverbed itself. The Federal government originally surveyed many flood plain lands, then sold them to homesteaders for development. Michigan, in receiving certain swamplands from the Federal government, sold these lands under the Swampland Act for reclamation and higher use and development. Recently, the Michigan Department of Natural Resources found that many of these flood plain lands, such as cattail marshes, are patented lands being filled or dredged to create additional saleable real estate and more recreational opportunities. These fills destroy valuable wildlife habitat on the flood plain and restrict the flood capacities of the river basin.

Under the present Michigan statutes, most of this type of development can be controlled to prevent substantial damage to the water resources. However, the pressure to develop flood plain properties for various purposes will continue until the Michigan legislature and

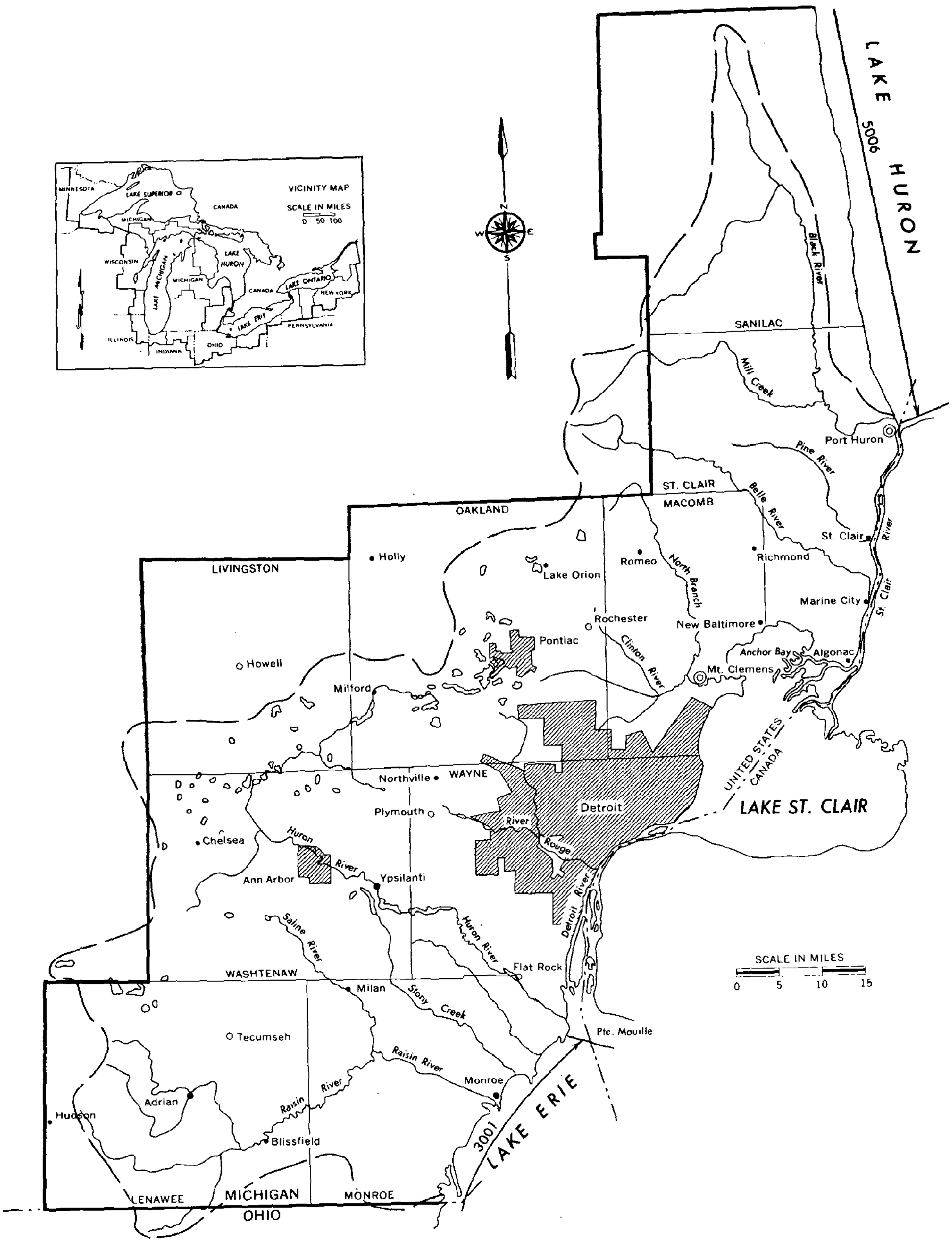


FIGURE 11-57 Planning Subarea 4.1

TABLE 11-54 Data Stations, Planning Subarea 4.1

Reach of Shore	Weather Station	Water Level Station	Reach No.
Pointe Mouillee, Mich. to Toledo, Ohio	Toledo, Ohio	Toledo, Ohio	3001

the courts further define the rights of the public and private interests. Probably more changes in the statutes and common law will be necessary to prevent undesirable development and filling.

Several rivers in the planning subarea experience severe flooding problems that are often complicated by ice jams. The most serious ice jams normally occur at a river's mouth, where littoral drift and lake ice may impede the flow of ice and flood the lower river. Lake level data, including the range and frequency of fluctuations at a locality, are required information for designing channel improvements and harbor structures.

The rapid increase in urbanization in metropolitan Detroit is changing the hydrologic character of the area, causing higher flood peaks and lower base flows in rivers and streams in the region by increasing the impermeable surface within the area. In addition, there is evidence that a heat-island effect causes excess rainfall over the Detroit area and exacerbates the problem. Future urbanization must be considered when analyzing flood problems here.

14.4 St. Clair-Detroit Rivers and Their Problems

The St.Clair-Detroit River system extends from the southern end of Lake Huron to Lake Erie, approximately 86 miles. The system is divided into three distinct parts: the St. Clair River, which has a length of 38 miles; Lake St. Clair, with a distance of 16 miles between the St. Clair River and the head of Detroit River; and the Detroit River which extends 32 miles to Lake Erie. From the Lake Huron level to Lake St. Clair, the fall is five feet; from the Lake St. Clair level to Lake Erie, the fall is three feet. The slopes along the water-surface profiles of the St. Clair and Detroit Rivers are relatively uniform in distribution with no rapids or falls.

One generally considers the St. Clair River in three reaches. The contracted upper reach, extending downstream four miles from Lake Huron, is 800 feet wide at the narrowest and has mid-channel depths varying from 30 to 70 feet. The middle reach extends downstream over the next 23 miles, is ½ mile wide, and has channel depths varying from 27 to 50 feet. This reach also contains Stag Island, Fawn Island, and a middle-ground shoal opposite the City of St. Clair, Michigan. The lower reach extends 11 miles to Lake St. Clair, where the river begins to divide into a number of distributaries that flow across the delta-shaped area called the St. Clair Flats.

Lake St. Clair is wide and relatively shallow, with average depths of 10 feet. It covers 430 square miles. The drop in level in the 16 miles of the lake from the Flats to the Detroit River is nearly 0.1 foot. The shallow depth of the lake requires a dredged navigation channel throughout its length.

Except at its head, where Peche Island and Belle Isle are located, the upper 13 miles of the Detroit River has an unbroken cross-section, is approximately one-half mile wide with channel depths varying from 27 to 50 feet. In the lower 19 miles, from the head of Fighting Island to Lake Erie, the river broadens and is characterized by many islands and shoals created by an extensive limestone outcrop. The improved main navigation channels through the lower river are on the west side of Fighting Island and the east side of Grosse Ile. In both the St. Clair and Detroit Rivers, except for man-made changes, natural channels have remained unchanged due to the heavy blue clay of their beds.

Many factors contribute to the formation of ice cover and ice jams in this river-lake system. During the cold weather water from Lake Huron rapidly cools when it enters Lake St. Clair due to its shallowness. As a result, ice enters the Detroit River from Lake St. Clair before it occurs on the St. Clair River. Lake St. Clair ice causes minor ice retardation in the lower part of the Detroit River in the early winter. However, it eliminates the source of supply except for a small amount produced in the shallow, low-velocity portions of the river. As the winter progresses, Lake St. Clair becomes ice-covered and the cover extends upstream into the channels of the lower reaches of the St. Clair River, to an extent dependent on the winter's severity and the water velocity which may preclude ice formation. This indigenous ice seldom extends above Recors Point.

As the winter progresses and heat transfers from Lake Huron, prevailing northerlies move the ice toward the bell-shaped exit into the St. Clair River. There, large sheets of ice lodge against the ice anchored to both shores and eventually bridge the expanse of water across the entrance. At Fort Gratiot, Michigan (head of St. Clair), the river slope begins, limiting the downsteam extension of the ice cover. The transverse distribution of the velocity at the entrance causes an arch-shaped ice cover. Additional ice contributed by the lake exerts horizontal pressure on the arch, strengthening and enlarging it. The expanse of ice extending into the lake absorbs and dissipates the destructive force of the winds and protects the arch. The reach below the ice arch on Lake Huron is ice-free (except for areas of shore ice) downstream to the limit of the indigenous ice cover formed in the river's lower reaches. This cover is extended upstream by the release of ice from Lake Huron.

The arch is periodically destroyed when the wind changes suddenly from the prevailing northerly to southerly. This south wind acts along the open water below the arch, exerting uneven pressure against its edge and causing it to fracture. When the wind shifts back to northerly, the broken ice is pushed into the river.

As the broken ice reaches the ice cover of the lower river, pieces are pushed against it. Those that lodge vertically extend below the bottom of the ice cover and trap pieces shoved under the ice pack. In extreme cases, this process continues until the river flow may be reduced by half. Ice jams are eroded by increased velocity across the jam area caused by the increased differential in head until an equilibrium condition is reached. Ice not trapped passes under the ice cover, through the improved channels in the lower St. Clair River into Lake St. Clair.

14.4.1 Current Velocities of Detroit and St. Clair Rivers

The approximate average current velocities in miles per hour through the different reaches of the Detroit River are: 1.9 mph in the Livingstone and Amherstburg Channels; 1.8 mph under the Ambassador Bridge; 1.4 mph in the Fleming Channel; and 1.4 mph at Windmill Point. The St. Clair River has a velocity of 2 mph through the channel entering Lake St. Clair and a velocity near its upper end of 4 mph through the rapids section extending from about 1,000 feet above to 200–300 feet below the Blue Water Bridge at Port Huron, Michigan. At intermediate points, the velocity varies irregularly. During periods of sustained high north-to-northeasterly winds on Lake Huron, velocities in the upper St. Clair River increase.

14.4.2 Legal Demarcation between the St. Clair-Detroit Rivers and Great Lakes

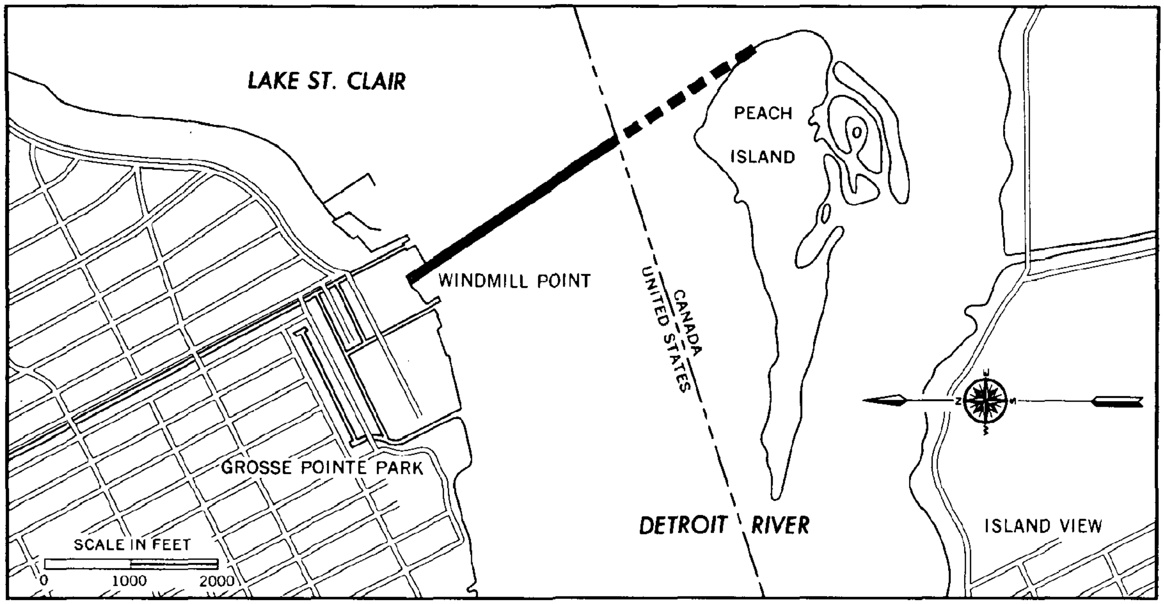
The State of Michigan has designated the boundary between the St. Clair and Detroit Rivers and the Great Lakes for the purpose of administering appropriate statutes. Figure 11–58 shows the separation of the Detroit River from Lake Erie and Lake St. Clair, and Figure 11–59 shows the separation of the St. Clair River from Lake St. Clair and Lake Huron. The separation is necessary for defining boundary areas of inland rivers under the Statute Act 291, P.A. 1965, whereas Act 241, P.A. 1955, as amended, applies to the Great Lakes water areas.

14.4.3 Fills on St. Clair-Detroit Rivers

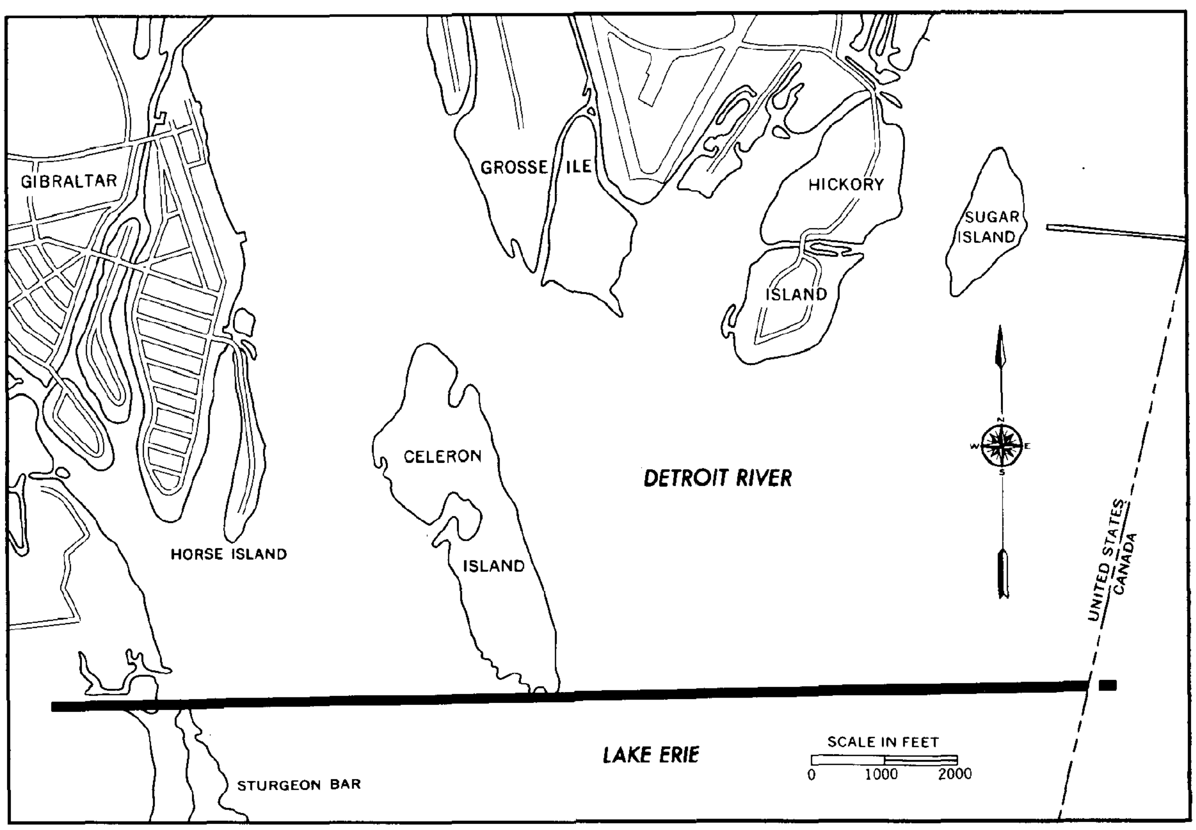
Possible cumulative effects of future land-bulkhead line fills on the St. Clair-Detroit Rivers and the channel regime are of concern. In recent years, the Corps of Engineers has been evaluating such applications for fill permits in cooperation with the State of Michigan to determine possible effects on the channel.

Fills shoreward from the Detroit River harborline now require a Federal permit. Previously Michigan required only a State permit. This helps control shoreline ownership.

The Secretary of the Army was authorized to establish harborlines to fix the limit to which piers, wharves, bulkheads, or other work might be extended into navigable waters without requiring Federal authorization (Corps of Engineers navigation permits). Since the establishment of the Detroit River harborline, Michigan has had considerable difficulty protecting natural resources along the Detroit River. The harborline limit for the Detroit River reached an offshore depth of 12 feet. The normal property boundary for the Detroit River has been the water's edge. For example, in the past many riparians on the Detroit River have assumed that the harbor-

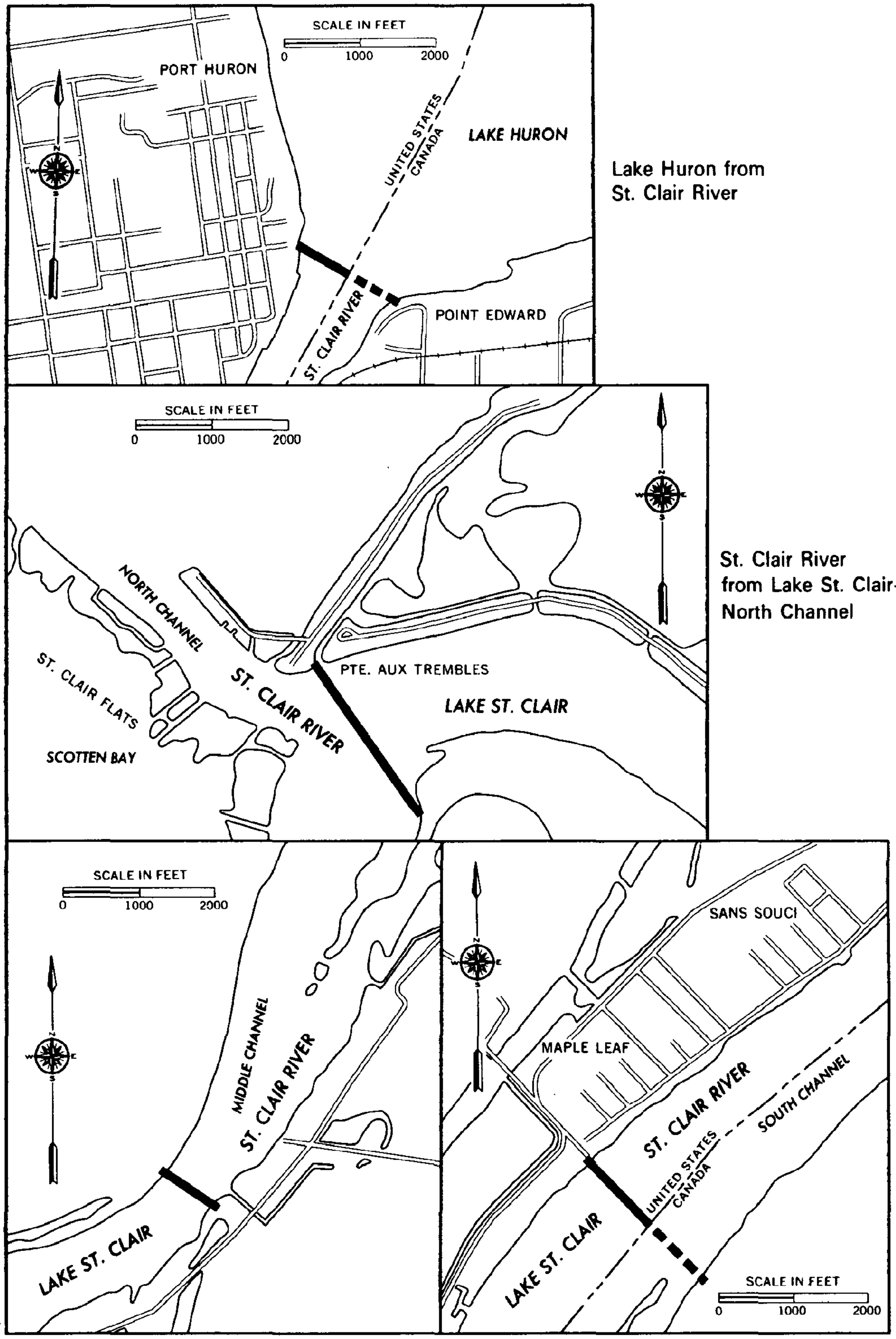


Lake St. Clair from Detroit River



Detroit River from Lake Erie

FIGURE 11-58 State of Michigan Legal Demarcation—Detroit River from the Great Lakes



Lake Huron from St. Clair River

St. Clair River from Lake St. Clair—North Channel

St. Clair River from Lake St. Clair—Middle Channel

St. Clair River from Lake St. Clair—South Channel

FIGURE 11-59 State of Michigan Legal Demarcation—St. Clair River from the Great Lakes

line limit was blanket authority to extend their property by filling to this limit. This has caused encroachment into the State's public navigable waters. Considerable filling resulted over the past 50 years, generally extending the natural river bank to the harborline. This past practice, now under control, has significantly changed the shoreline features of the Detroit River.

14.4.4 Commercial Dredging in St. Clair River

In the past, commercial dredging of gravel from the St. Clair River has increased the hydraulic capacity of the river and lowered the levels of Lakes Michigan-Huron. The 1926 Report of the Joint Board of Engineers attributes a 0.3-foot reduction of the levels of Lakes Michigan-Huron to these activities. Dredging of gravel from the reach of the St. Clair River in the vicinity of the Point Edward docks (at the head of the river) occurred during the period 1908–1925.

Removals of sand and gravel aggregates in the lower portions of the South Channel, St. Clair River, during the past decade have involved only minor amounts and have had no effect on the river's regimen. In each case, the State of Michigan's easement granted for this type of activity (Act 236, P.A. 1913) was also covered under a Federal permit (navigation) issued by the Corps of Engineers. Michigan has stopped issuing such easements by administrative decisions.

14.4.5 Proposed Compensation for Lower Levels of Lakes Michigan-Huron Due to Dredging

Since 1933, there have been two dredging projects in the St. Clair-Detroit River system to provide for deeper draft commercial navigation which has lowered the levels of Lakes Michigan-Huron.[26] Agreement in principle exists between the United States and Canada whereby the United States will undertake, as an integral part of these dredging projects, the installation of compensatory works to offset the effects of increased channel depths. This compensatory part of the dredging projects has not been carried out as yet because the extent of the effects remains to be coordinated and agreed upon between Canada and the U.S., the best method of compensation remains to be determined, and the matter merited a deferred decision in light of the comprehensive systems approach being developed by the ongoing IJC Great Lakes levels study, *Regulation of Great Lakes Water Levels.* It would not be reasonable to provide compensation without considering the overall context of probable future major international regulation projects.

The method of compensation generally mentioned in the past is to place sills at hydraulically strategic points in the river to restore the system to its 1933 status. However, the intensive studies the IJC is conducting have recently facilitated increased understanding of the problems involved. An alternative method may be preferable—building a gated structure in the St. Clair River. Navigation considerations, slope requirements, and site conditions would determine its location. The main advantage would be that this structure (which would provide only partial control in the St. Clair River) would be operational at times of high water, whereas sills would become useless and might have to be removed at considerable cost.

14.4.6 Proposed Trenton Channel Navigation Project

The Trenton Channel is in the lower Detroit River west of Grosse Ile. The present navigation channel begins at the upstream end, above Grosse Ile, where it connects with the main channel of the Detroit River. Project depths of 27 and 28 feet are maintained downstream to a turning basin at the McLouth Steel Plant. From this turning basin a project depth of 21 feet is maintained to a lower turning basin at the Detroit Edison thermal plant 1,700 feet below the Grosse Ile lower bridge, where the dredged portion of the channel terminates. Below the lower turning basin the channel shoals to less than 10 feet, and low, swampy Celeron Island divides the flow before it discharges into Lake Erie.

Plans for the improvement of the Trenton Channel are variations of three basic channel changes:

(1) channel extending from the existing lower turning basin to the navigation channel in Lake Erie

(2) channel extending 8,000 feet downstream from the lower bridge and terminating in a turning basin

(3) channel from the present navigation channel in Lake Erie terminating in a turning basin just above Gibraltar, Michigan

Final design of such a project should con-

TABLE 11-55 Data Stations, Planning Subarea 4.2

Reach of Shore	Weather Station	Water Level Station	Reach No.
Pointe Mouillee, Mich. to Toledo, Ohio	Toledo, Ohio	Toledo, Ohio	3001
Toledo, Ohio to Sandusky, Ohio	Toledo, Ohio	Toledo, Ohio	3002
Sandusky, Ohio to Erie, Pa.	Cleveland, Ohio	Cleveland, Ohio	3003

sider the effects of the channel improvements upon the water levels, velocities, flow distributions, and the compensation works required to offset the channel enlargements. From the levels and flows standpoint, these are factors one must consider in the design of the project.

14.4.7 Proposed Regulatory Works for Lakes Michigan-Huron

The present International Joint Commission study, *Regulation of Great Lakes Water Levels*, is considering regulatory works sites for the St. Clair and Detroit Rivers described in a Corps of Engineers report.[42]

Because of riparian use and developments along the St. Clair and Detroit Rivers and along the shores of Lake St. Clair, control structures would be needed at several points along the system to keep variation of the regulated rivers and Lake St. Clair levels within acceptable limits. Since the St. Clair-Detroit River system carries considerable commercial traffic any regulatory works that would delay navigation would have a large economic impact.

The slopes along the St. Clair and Detroit Rivers are relatively flat. Their distribution along the profile is fairly uniform except near the head of the St. Clair River. Here the slope is substantially greater than those in the lower part of the system. Such conditions necessitate a combination of control structure sites. The 1965 Corps of Engineers Report lists possible control structure sites of the St. Clair River at Point Edward, Stage Island, St. Clair Middle Ground, Fawn Island, S.E. Bend Channel, and North and Middle Channels. Possible control structure sites of the Detroit River include Stony Island and Trenton Channel.

14.5 Planning Subarea 4.2

Planning Subarea 4.2 consists of the following drainage areas: Maumee River, Toussaint-Portage Complex, Sandusky River, Huron River, and Vermilion River (Figure 11-60).

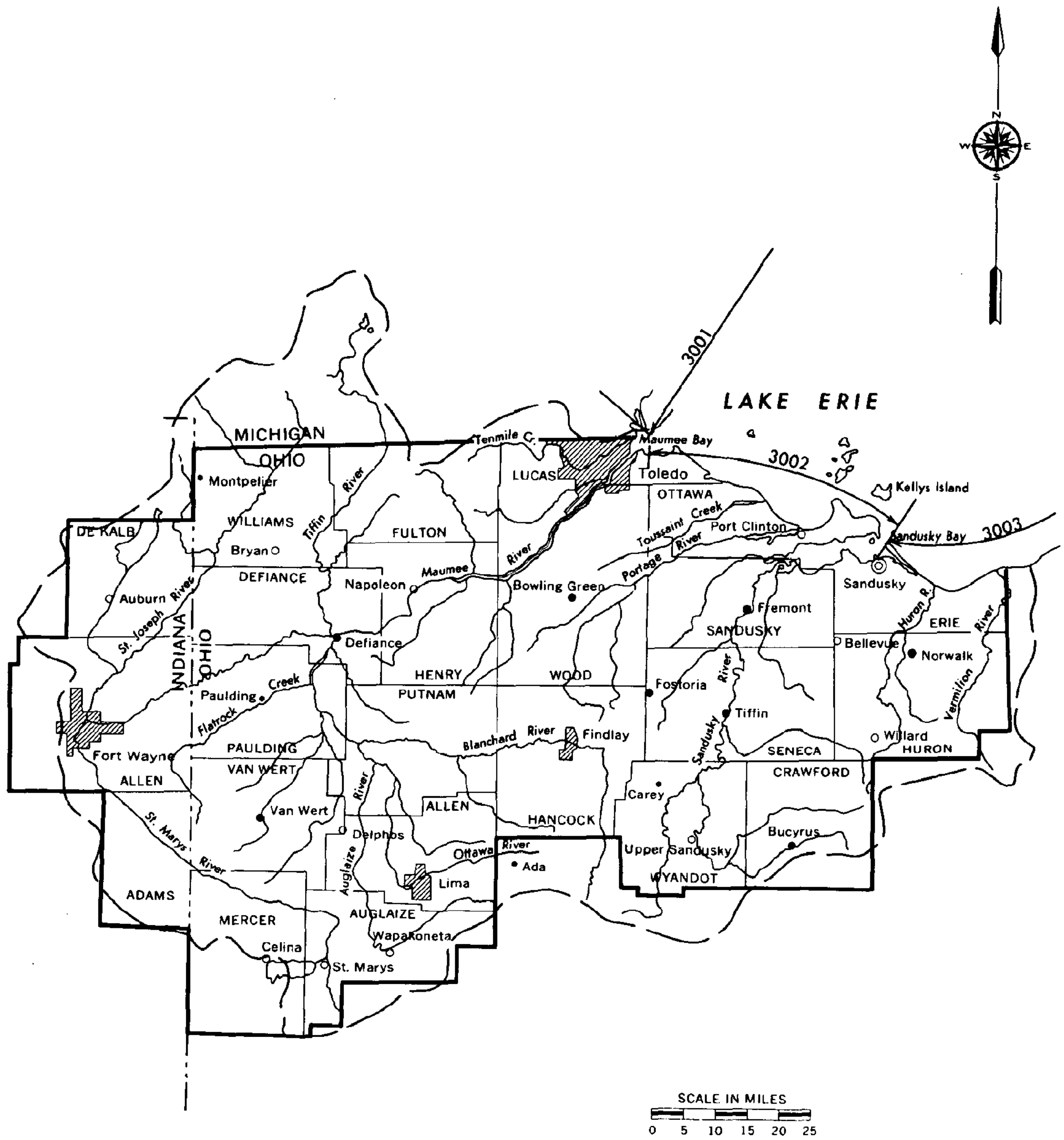
14.5.1 General

Ultimate storm water level data for the Lake Erie shore of Planning Subarea 4.2 were computed with data from Table 11-55.

The highly unpredictable currents in Toledo Harbor are a commercial navigational hazard. The principal problem area is near the lakefront and C and O Docks at the mouth of the Maumee River, where currents affect vessels entering and leaving the docks. The primary generating forces are brief water level oscillations (wind tides, surges, and seiches) in Lake Erie and discharge from the Maumee River. The highest current speeds occur during the formation of a wind tide in strong southwest winds (rapidly falling water level) along with a significant discharge from the Maumee River.[30] Current velocities greater than 0.8 foot per second occur near the lakefront and C and O Docks. A recent study reports that a current-indicator system in the harbor is feasible.

During periods of water level oscillation in the vicinity of Sandusky, Ohio, similar hazardous currents occur in the entrance to Sandusky Harbor. The outlet to Sandusky Bay retards water outflow during decreasing water levels on Lake Erie due to the constricted opening of the bay mouth. Velocities of 0.6 foot per second are not unusual at the entrance to Sandusky Bay.

Serious beach and shore erosion problems exist along the entire shoreline of Planning



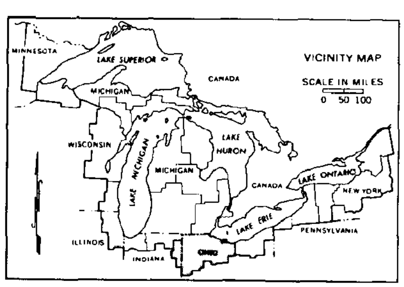


FIGURE 11-60 Planning Subarea 4.2

TABLE 11–56 Data Stations, Planning Subarea 4.3

Reach of Shore	Weather Station	Water Level Station	Reach No.
Sandusky, Ohio to Erie, Pa.	Cleveland, Ohio	Cleveland, Ohio	3003

Subarea 4.2 except near Marblehead Peninsula and Catawba Island in Ottawa County, Ohio, and along the islands (North, Middle, and South Bass Islands), where the shores consist of limestone cliffs. West of Sandusky Bay, except for the limestone shores of Marblehead and Catawba Island, the land is low and there are no rock outcrops along the shores, which are essentially clay. In some places only narrow barrier beaches separate marshes from the Lake. Dikes protect some of the low areas. Maumee Bay, at the west end of Planning Subarea 4.2, has banks of low, easily eroded clays.

Development of flood plain areas with no alternate routes for flood flows causes most flood problems in the Sandusky River basin. Because of the flat slope of the river, velocities are relatively low between Fremont and the mouth of the river, forming ice jams and frequently causing abnormal flood stages in Fremont. The level of Sandusky Bay influences this situation. Floods occur on the average of once every 1½ to 2 years along the river. A Federal project has been adopted, with construction started in 1970, for flood protection along the Sandusky River at Fremont, Ohio, to provide for enlargement of the channel, protective floodwalls, and other improvements.

A problem of ice jamming on the Maumee River occurred below Perrysburg, Ohio, in 1958 and previous years. Lake Erie level influences the level of the lower portion of the Maumee River. Problems generally exist in restricted channels of the Maumee River where islands or other natural obstructions occur. Ice jamming problem areas need to be defined on tributaries in order to avoid adding to this problem by future development of river frontage.

14.6 Planning Subarea 4.3

Planning Subarea 4.3 consists of the following drainage areas: Black-Rocky Complex, Cuyahoga River, Chagrin Complex, Grand River, and Ashtabula-Conneaut Complex (Figure 11–61).

14.6.1 General

Ultimate storm water level data for the Lake Erie shore of Planning Subarea 4.3 were computed utilizing data from Table 11–56.

Serious beach and shore erosion problems exist throughout the entire shoreline of Planning Subarea 4.3 except near the mouth of the Rocky River (Edgewater Park in Cleveland to Huntington Park Beach) where the shore consists of shale cliffs. Erosion of bluffs and shorelands increases or decreases as the lake level rises or falls. During periods of high lake levels, storm-generated waves and currents cause recession of the upland areas. At low lake levels, the rate of recession is much less, but once eroded, upland areas remain lost.

Major flooding has accompanied ice jams at Lakewood and Rocky River, Ohio at the mouth of the Rocky River, and at Eastlake at the mouth of the Chagrin River. Flooding occurred as recently as January 1959 on the Rocky River, and January 1959 and January 1968 on the Chagrin River.

The mouth of the Rocky River was dredged for an improved boat navigation harbor in 1968. This increased the ice-discharging capacity of the river. Engineers are designing similar improvements for the Chagrin River.

14.6.2 Harbor Resonance

Harbors such as Conneaut, Ashtabula, and Fairport exhibit large oscillations, perhaps due to resonance within the harbor and external fluctuations. Local harbor resonance, progressive within the harbor, may produce higher water levels within the harbor than in the Lake. Piers and docks of small inlets within the harbor may amplify resonance. These sudden disturbances cause navigation hazards.

From 1939 to 1951 the Lake Carriers Association reported 180 accidents at the entrance to Conneaut Harbor.[49] It is believed that crosscurrents at the entrance to Conneaut as well as short-period fluctuations within the harbor caused many of these. It seems that vessels entering Conneaut Harbor are caught in out-

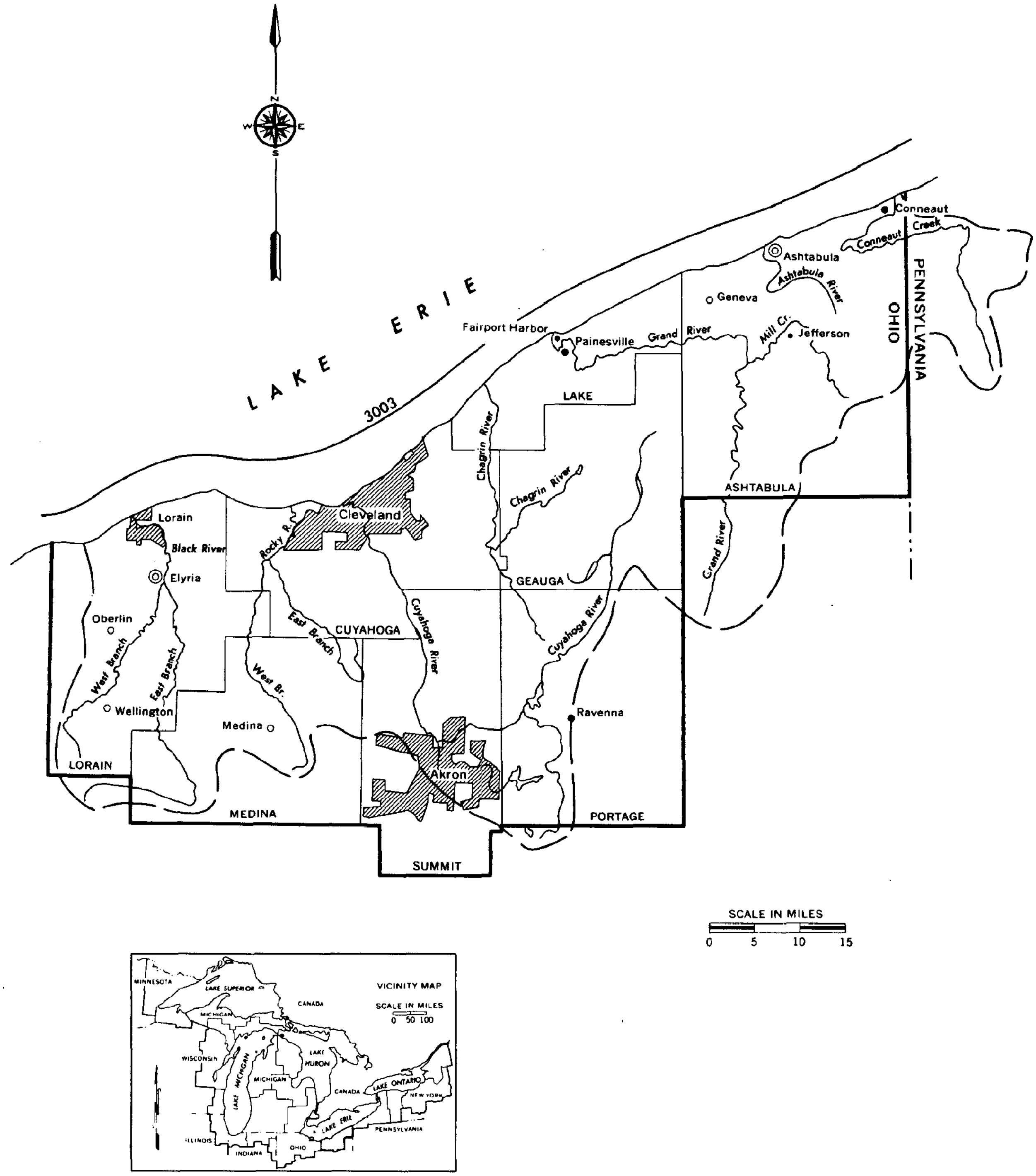


FIGURE 11-61 Planning Subarea 4.3

flowing or inflowing currents produced by a higher fluctuation in the harbor than in the Lake. These short fluctuations occur three or four times more often than the larger fluctuations at Buffalo, but are associated with these changes. Harbor resonance generated by seiches also causes lake level fluctuations at Conneaut. It is known that these disturbances produce different fluctuations at Fairport, Ashtabula, and Conneaut. Verber reports a 1.3-foot rise in forty-five minutes on March 7, 1955, in Conneaut Harbor. An 8.2-foot rise occurred during the period of record at Buffalo, with substantial lowering at the opposite end of the Lake at Toledo. During such an extreme rise at Buffalo, the estimated rise by extrapolation would be 1.1 feet at Ashtabula and 2.0 feet at Conneaut.

14.7 Planning Subarea 4.4

Planning Subarea 4.4 consists of the following drainage areas: Erie-Chautauqua Complex, Cattaraugus River, and Tonawanda Creek. Figure 11–62 is a map of this planning subarea.

14.7.1 General

Ultimate storm water level data for the Lake Erie shore of Planning Subarea 4.4 were computed utilizing data from Table 11–57. Ultimate water levels were not computed for the shoreline from Erie, Pennsylvania, to Buffalo, New York, in the IJC study, *Regulation of Great Lakes Water Levels*. Ultimate water levels have been derived for this segment of shoreline for the Framework Study.

Serious beach erosion problems exist at Presque Isle, Pennsylvania. A cooperative beach erosion control project was originally authorized in 1954.[6] Seawalls and groins have been constructed and a continuing beach nourishment program established. The remainder of the shoreline in Planning Subarea 4.4 consists primarily of shale bluffs. The length of shore vulnerable to appreciable wave damage is small.

Serious flooding has accompanied ice jams on the Buffalo River and its tributaries. These jams normally occur in shallow areas, and lake stages do not affect them. The most recent major damage occurred in January 1959. Other serious flooding problems occur on Tonawanda Creek and its tributaries, Ellicott, Bull, and Mud Creeks. Severe ice jams occur at the mouth of Cattaraugus Creek, where littoral drift and lake ice impede the flow of ice and storm discharge. Serious damage occurs almost every other year with the last major damage in 1968. A small-boat navigation improvement and levees to provide flood protection are nearly completed at Cattaraugus Creek.

14.7.2 Niagara River

The Niagara River, which is 36 miles long, flows northward out of the northeast end of Lake Erie into the southwest end of Lake Ontario. The fall of the river, taken at the respective mean levels of Lakes Erie and Ontario for the years 1900 to 1969, is 325.61 feet. Details of the approximate fall are shown in Table 11–58 based on mean levels for Lake Erie as determined by the Buffalo District, Corps of Engineers.

Just below Goat Island the Niagara waters descend rapidly to the level of Lake Ontario, through the rapids above the Falls, the great Falls themselves, and the rapids below the Falls whose approximate descents are: upper rapids, 50 ft; Niagara Falls, 182 ft. (during 100,000 cfs flow over Falls); lower rapids, 83 ft.; Niagara River below Lewiston, 0.5 ft.

During the 110-year period from 1860 to 1969 the discharge of the Niagara River averaged 201,900 cubic feet per second. The currents in the Niagara River from its head to the foot of Squaw Island are strong and somewhat variable, and the bottom is generally rocky. The channel in the open river is shallow, and navigation is hazardous. The Black Rock Canal affords an alternate deep route from Lake Erie at Buffalo to the foot of Squaw Island, where it connects with the river by means of a ship lock accommodating large vessels. Its present available depth is 21 feet.

14.7.2.1 Federal Navigation Project

Navigation improvements from the head of the Niagara River at Buffalo, New York to Tonawanda, New York provide a channel 21 feet deep from the Buffalo north entrance channel to a point opposite Sixth Avenue in North Tonawanda, having a total length of 13½ miles and width of 200 feet or more. The improvement encompasses the Lake Erie entrance; Black Rock Canal and ship lock; the east channel of the river from the foot of Squaw Island through Strawberry Island Reef to deep water below Rattlesnake Island

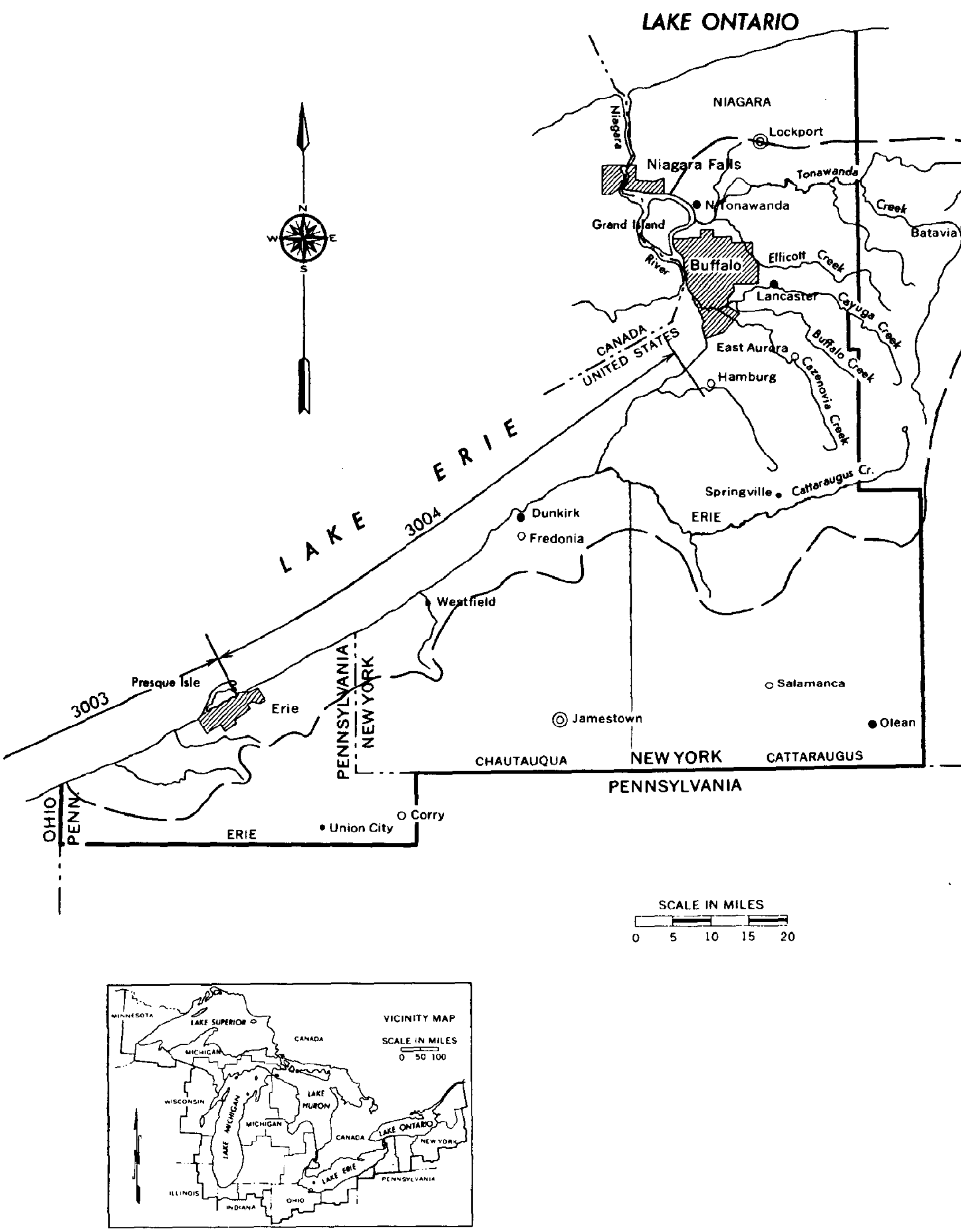


FIGURE 11-62 Planning Subarea 4.4

TABLE 11-57 Data Stations, Planning Subarea 4.4

Reach of Shore	Weather Station	Water Level Station	Reach No.
Sandusky, Ohio to Erie, Pa.	Cleveland, Ohio	Cleveland, Ohio	3003
Erie, Pa. to 11 miles south of Buffalo, N.Y.	Buffalo, N.Y.	Erie, Pa.	3004

TABLE 11-58 Niagara River Profile

From Lake Erie	Distance in Miles	Approx. Fall in Feet
To Peace Bridge	2.0	3.4
To Foot of Squaw Island	4.0	5.7
To Head of Grand Island	6.3	6.4
To Head of Tonawanda Island	12.1	7.2
To N. Grand Island Bridges	18.8	9.5
To Head of Goat Island	22.4	16.1

Shoal; and a channel through the shallow area in the river on the west of Tonawanda Island, terminating in a turning basin below the foot of the island at North Tonawanda. The New York State Barge Canal System utilizes the mouth of Tonawanda Creek as its entrance. Tonawanda Creek is used as the canal to Pendleton, New York, where the artificial channel begins.

Black Rock Canal lies along Buffalo's Niagara riverfront. It is generally parallel to the river, separated by Bird Island Pier and Squaw Island. These retain the canal pool on the west end, and with the Black Rock Lock, serve to keep the canal level the same as the water surface of Lake Erie. Black Rock Lock, connecting the canal with the river near the foot of Squaw Island, is 650 feet long (usable length 625 feet), 70 feet wide (68 feet in the clear), with 21.6 feet depth over miter sills and an average life of 5.2 feet.

14.7.2.2 The Treaty of 1950 Concerning Niagara River

The Treaty of 1950 between Canada and the United States concerning uses of the waters of the Niagara River was signed on February 27, 1950. By its provisions it ended the limitations on diverting Niagara River water for power in accordance with Article V of the Treaty of 1909. It replaced temporary international agreements for the allocation of the Niagara River for power purposes. In accordance with provisions of Article VII of the 1950 Treaty, a representative was appointed by each government. Acting jointly, these representatives determine the amounts of water available for Treaty purposes, and record the amounts of water used for power diversions. By an exchange of notes during January 1955, the two governments officially designated the representatives as the International Niagara Committee.

With regard to flows and diversions, the Treaty of 1950 became effective October 10, 1950. Under this treaty all waters in excess of certain minimum flows needed to maintain the scenic spectacle at Niagara Falls are available for power diversion and, with the exception of the 5,000 cubic feet per second (Ogoki-Long Lake Diversions into Lake Superior) authorized in 1940 for Canadian diversion, are to be allocated equally between the two countries. If the power development of one country cannot use its total allocation, the other country may use what is left. Minimum flows over the Falls are not to be less than 100,000 cubic feet per second between 8:00 a.m. and 10:00 p.m. Eastern Standard Time, from April 1 to September 1, and 8:00 a.m. to 8:00 p.m. from September 16 to October 31. At all other times, the flow over the Falls is to be at least 50,000 cubic feet per second.

The International Niagara Committee receives daily reports of operations of the hydroelectric generating stations on the Niagara River that divert water above Niagara Falls, and the DeCew Falls plant in Canada that diverts water from Lake Erie through the Welland Canal. The Committee checks these reports submitted by the power entities. These reports show the quantities of water diverted each hour, and from this, the Committee prepares monthly and annual summaries. Monthly values for diversions by the New York State Barge Canal and the Welland Canal for purposes other than power are also included in the summaries.

Committee representatives inspect all plants bi-weekly and intermittently to obtain independent watt-meter readings for power output and to assure compliance with all Treaty provisions and periodically check gages used to compute flows. These checks are in-

TABLE 11–59 Power Generating Installations

Station	Capacity in Kilowatts	Average Head in Feet
United States		
Robert Moses	1,950,000	300
(Pump Storage)	240,000	75
Canada		
Sir Adam Beck I	441,000	295-298[1]
Sir Adam Beck II	1,200,000	294-297[1]
(Pump Storage)	170,000	50-75[2]
		60-85[3]
Ontario Power	135,000	205-230[1]
Canadian Niagara	80,000	189-208[1]
Toronto	108,000	135
DeCew Falls I	36,000	266
DeCew Falls II	120,000	283

[1]Varies with flow over Niagara Falls - 50,000 cfs minimum at times, 100,000 cfs minimum at other times

[2]100,000 cfs

[3]50,000 cfs

corporated into the existing power inspection schedule and include the storage reservoirs and low-head plants, as well as the high-head plants.

14.7.2.3 Power Projects

There are five hydroelectric power plants (U.S. and Canadian) using Niagara River water, and one plant utilizing Welland Canal water. All Niagara River hydroelectric power plants divert water from above the Falls. The diverted water runs through the turbines and is returned to the river below the Falls. Terminology divides the plants into the two types, high-head and low-head. The high-head plants of the Power Authority of the State of New York at Lewiston, New York and the Hydro Electric Power Commission of Ontario at Queenston, Ontario use most of the diverted water and nearly all of the difference in elevation between the Lakes (approximately 300 feet of the available 326 feet), returning water to the river below the Whirlpool Rapids. The low-head plants in Canada divert their water for power purposes just a short distance upstream of the Falls and discharge into the Maid-of-the-Mist Pool at the foot of the Falls, where the water elevation is approximately 76 feet higher than below the Whirlpool Rapids.

The low-head plants generate 7 to 12 kilowatts of electrical power per cfs of water. The high-head plants produce 22 to 24 kilowatts of power per cfs. Data on the Niagara River and Welland Canal power generating installation are summarized in Table 11-59.

Figure 11–63 is a map showing the location of the Niagara River power plants. An estimated dollar value of additional flow for power purposes on the Niagara River is provided in Figure 11–75.

14.7.2.4 Chippawa-Grass Island Pool

When the flow over the Falls is changed from 50,000 cfs to 100,000 cfs or vice versa in order to comply with the Treaty, the level of the Maid-of-the-Mist Pool suddenly changes more than ten feet and outflow no longer equals inflow.

The four miles of river from the lower end of Grand Island to the head of the Cascades opposite the upstream end of Goat Island is known as the Chippawa-Grass Island Pool. The high-head hydroelectric power plant intakes are in this pool. On the Canadian side, near the downstream end of the pool, the Niagara River control structure extends into the river at right angles to the shore for 2,000 feet. Except for an approach fill adjacent to the shore it consists entirely of piers and 18 movable control gates. The control structure which was constructed as a result of the Treaty of 1950 compensates for the large power diversions, maintains natural levels in the upper Niagara River, and expedites the twice-daily changes in flow over the Falls during the tourist season. The approximate elevation of the water level of the river at the control structure is 561.5 feet. If this level is exceeded, the water level is beyond the capacity of the control gates. The low-head Canadian plants must thus operate to utilize flows in excess of the Treaty requirements, or the additional water will be lost for power-generating purposes. The performance of the control structure during 1968 averaged 750 cfs in excess of Treaty flows over the Falls. The power entities operate the control structure to maintain the pool at normal levels within the tolerances set by the International Niagara Board of Control. The International Joint Commission[14] established this Board to supervise the construction, maintenance, and operation of remedial works provided on the Niagara River under the 1950 Treaty with Canada. The established tolerances are ± 0.5 foot for the daily mean, and ± 0.3 foot for the monthly mean.

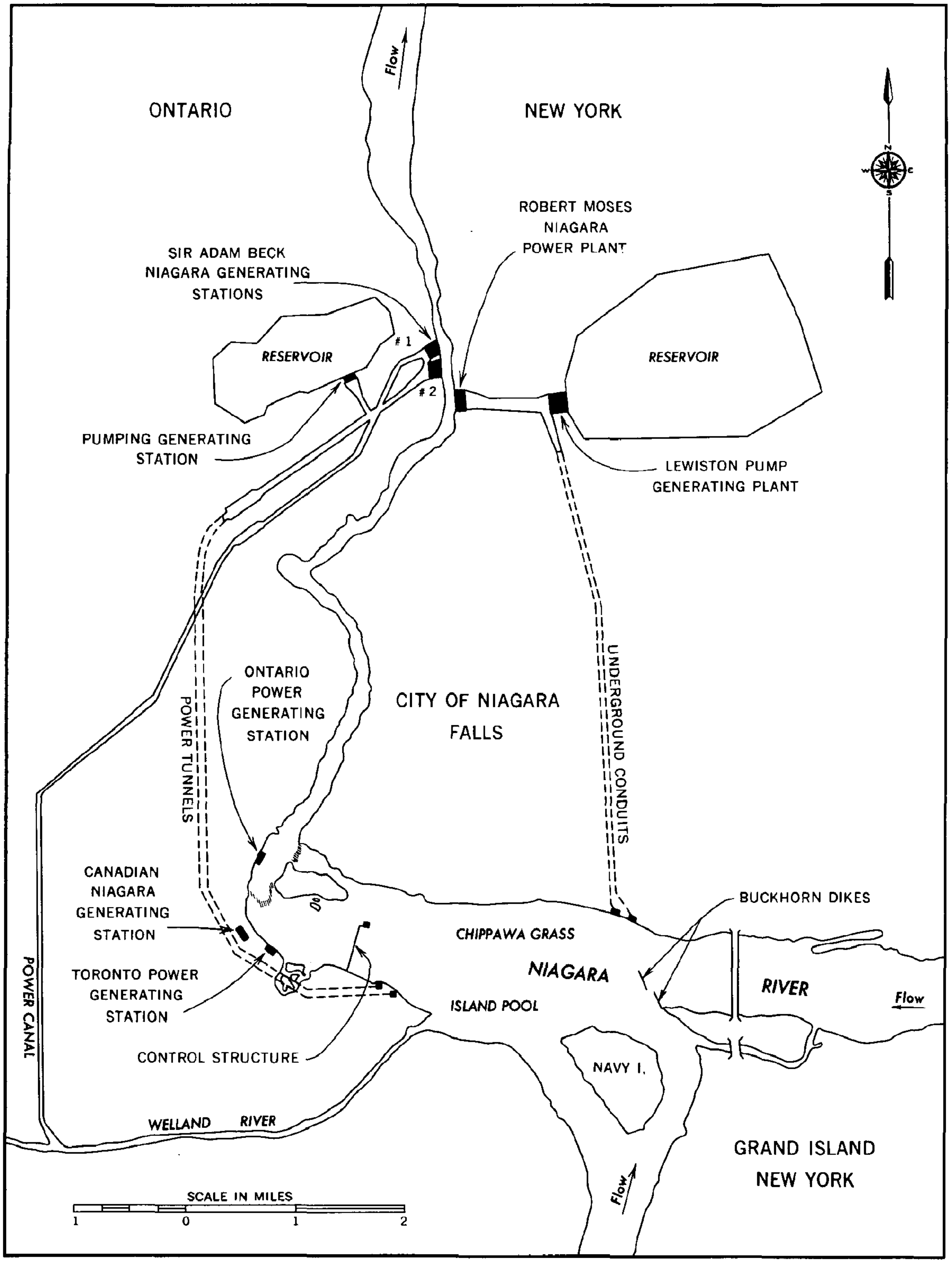


FIGURE 11–63 Niagara River Power Plants

The average fluctuation (range from the lowest to highest level) at the control structure on a daily basis is approximately 1 to 1½ feet. The extreme fluctuation experienced at the control structure caused by low levels or storm conditions over Lake Erie may vary three feet.

The New York State Department of Environmental Conservation representative from Avon, New York, has commented on the range of fluctuations in the upper Niagara River as the result of power diversions and the effects of these fluctuations on the fish habitat. The main concern is the bass fisheries spawning period that occurs between May and July. It was stated that the present power operations have had no detrimental effects on the fish habitat.

Extensive studies have been under way since 1967 by the Corps of Engineers and the Water Survey of Canada to determine the backwater effect in the upper Niagara River and Lake Erie produced by manipulation of the Chippawa-Grass Island Pool. Several methods of determining this effect have been tried, and further study is required. Field measurements have also been made to check the summer weed retardation effect on upper Niagara River flows. The degree of weed effect is necessary in order to determine a suitable permanent method for controlling the level of the Chippawa-Grass Island Pool. Also, ice retardation in the winter must be taken into consideration.

14.7.2.5 Lake Erie-Niagara River Ice Boom

Lake Erie has an area of approximately 10,000 square miles, most of which becomes ice-covered during a normal winter. The ice near the Niagara River entrance usually arches from shore to shore, preventing ice from passing from the Lake into the river. Under especially adverse conditions of wind, temperature, and ice thickness, this arch and the ice behind it break, and large quantities of ice (up to 40 square miles per day) flow down the Niagara River. The Niagara River above the Falls cannot carry ice at this rate for more than a few hours without serious blockages. The Power Authority of the State of New York and the Hydro Electric Power Commission of Ontario constructed the Lake Erie-Niagara River ice boom to prevent the mass movement of ice from the Lake to assist in reducing ice damage in the Niagara River. Before construction of the ice boom in 1964, the flow of Lake Erie ice into the Niagara River seriously damaged shoreline property and reduced power production from blockages at the intakes. The largest recent ice jam flood was in March 1955. Other serious damage occurred in April 1909, April 1928, May 1942, and January 1962 and 1964. The ice boom is designed to help consolidate the early ice cover on the Lake so that it does not break up and move down the river. Under strong winds ice will override the boom, but as the winds subside the boom will rise and reduce the flow of ice.

The ice boom is placed in position in December and opened in April or early May. Since construction of the ice boom, there has been relatively little damage to shore property and power production. The ice boom is pictured in Figure 11–64.

14.7.2.6 Land Fills and Marine Structure Development along Upper Niagara River

Landfills along river frontages could change the river's hydraulic capacity. There is concern that cumulative effects could reduce flow and ice passage capacities down the Niagara, and raise levels on Lake Erie. The International Niagara Board of Control is investigating this because it exists on both sides of the river.

The State of New York and Federal agencies must review construction permits for landfills and marine structures along the Niagara River with consideration of their effects on discharge capacity. An alternative solution might include making approval for future permits dependent on payment of prorated costs for compensating measures required to maintain the river's hydraulic capacity.

14.7.2.7 Niagara River Gorge Natural Ice Bridge

Ice from Lake Erie that is carried down the Niagara River and swept over the Falls causes an ice build-up in the Niagara River gorge. Freezing river waters add extensively to this ice bridge. The Niagara River gorge ice bridge has occasionally caused physical damage, most recently in 1964 when ice rose 80 feet and extensively damaged Maid-of-the-Mist Pool facilities. Ice damaged the Ontario power plant in the gorge and jammed the river nearly solid to Youngstown, New York. With the installation of the ice boom, ice jamming has been substantially less on the lower Niag-

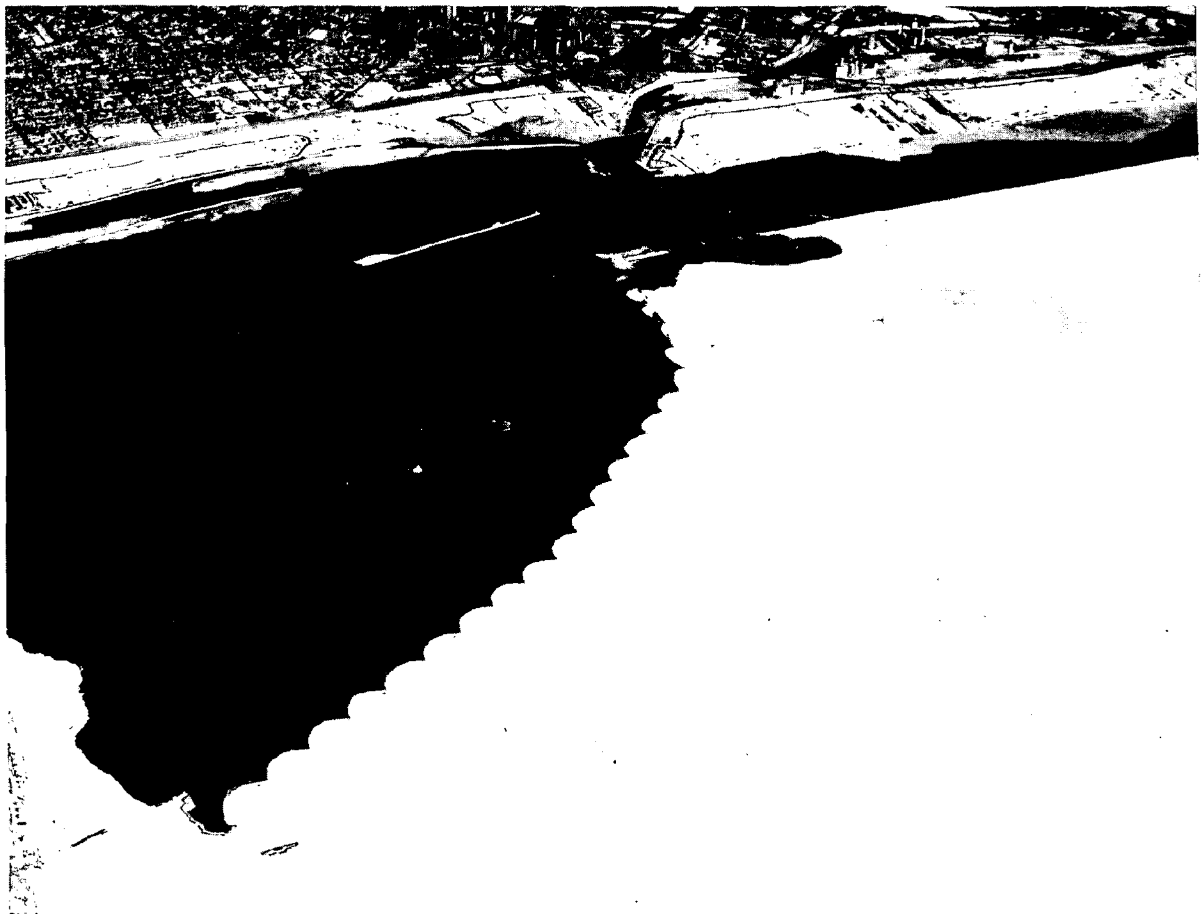


FIGURE 11–64 Niagara River Ice Boom

ara River, but no noticeable change has occurred to the natural ice bridge.

14.7.2.8 Niagara River below Niagara Falls

The lower Niagara River is navigable for seven miles from its mouth in Lake Ontario to Lewiston at the foot of the lower rapids. It has an unobstructed channel 1,500 to 2,000 feet wide and 30 to 70 feet deep, although the river entrance has a limiting depth of 13 feet. The area in Lake Ontario off the mouth of the Niagara River has extensive shoals within a three-mile radius. Commercial sand and gravel are dredged intermittently in the area, and the depths change. Commercial navigation is limited on the lower river.

The lower Niagara River reach, upstream from the Lewiston, New York-Queenston, Ontario area, is not considered navigable because of heavy rapids extending more than four miles.

The water levels of the river in the vicinity of Lewiston, New York, and Queenston, Ontario, fluctuate rapidly because of water discharges from high-head power plants due to their pump-storage power generating operations. These fluctuations average from 0.2 to 0.4 foot. Recreational navigation interests should consider greater utilization of the lower Niagara River.

14.7.3 Diversion from Lake Erie via Black Rock Navigation Canal

The Black Rock Navigation Canal at Buffalo is a means of diverting more waters from Lake Erie down the Niagara River when Lake Erie has high water levels. With a normal five-foot drop from the Lake Erie level to the lower end of the Black Rock Canal Lock it is possible to discharge approximately 15,000 cfs continuously. However, it would take a sector gate modification to accommodate such continuous flow because the lock is now equipped with miter gates. The present annual canal diversion for navigation is estimated at 10 cfs. The intake valve culverts for the lock under continuous flow could discharge approximately 700 cfs. It would cost little to accomplish this small increase in outflow from Lake Erie.

Use of the canal as an additional diversion channel would interrupt navigation. Local navigation between Tonawanda-Buffalo River makes limited use of the canal throughout the winter. Actual lock modification would cost $1,720,000, not including the cost to protect the lock walls against resulting higher water velocities. Detailed studies would be required to determine such cost and substantiate the cost, as well as to determine the benefits to be derived from such a project.

An alternative that provides greater flexibility, because it would not impede navigation, would be to excavate a new discharge canal across Squaw Island. This could lower construction costs to provide greater Lake Erie outlet capacity during high water periods. A control structure consisting of a 70-foot-wide weir section with a sill elevation of 546 feet was selected for this. The control gate would be of the tainter type, submersible to allow ice skimming. The scheme's estimated first cost is $1,714,000. An increase in the outflow from Lake Erie of 15,000 cfs for a period of seven months would lower the level of the Lake by 0.53 foot.

14.7.4 Welland Ship Canal, Ontario, Canada

This canal was constructed between 1913 and 1932 to supersede a former third canal that restricted the size of vessels passing between Lake Ontario and the Upper Lakes.[4] It crosses the Niagara peninsula generally in a north-south direction between Port Weller on Lake Ontario and Port Colborne on Lake Erie. The St. Lawrence Seaway Authority of Canada controls it.

The canal is 27.6 miles long and generally 200 feet wide at the bottom and 310 feet wide at the water surface. Its present depth is 27 feet with a permissible draft of 25¾ feet. There are eight locks, comprising seven lift locks located in the northern one-third of the total length at and below Thorold, and one guard lock about 1½ miles north of the Port Colborne entrance. The lifts vary from 43.7 to 47.9 feet, aggregating 327 feet. Any vessel no more than 730 feet in overall length, 75 feet 6 inches in extreme breadth, and 25¾ feet draft, including permanent fenders, may transit during the navigation season. Lock Numbers 4, 5, and 6 are twin locks in flight, overcoming the steep rise between Merriton and Thorold known as the Niagara escarpment, and permitting uninterrupted passage to both upbound and downbound traffic.

Lake Erie water reaches Lake Ontario through the Welland Canal and the tailrace of DeCew Falls hydroelectric power plant three miles west of the Welland Canal. The DeCew Falls plant draws its water from the Welland Canal. The amount of water the Welland Canal diverts from Lake Erie for navigation and power has averaged 7,290 cfs for the period 1959–1968. The computed effect of the Welland Canal (7,000 cfs) has lowered Lake Erie level by 0.32 foot and decreased the Niagara River outflow accordingly.

14.7.5 Study of Preservation and Enhancement of the American Falls, Niagara River

Before 1931 the American Falls had a fairly straight crest with a relatively unbroken fall to the pool below, although some debris was visible at the base. Rock falls beginning in 1931 have left the Falls with a jagged crest. Fallen rock obscures much of the base and has reduced the unbroken curtain height by half. Under the diversion conditions permitted by the 1950 Treaty, stages in the downstream pool may be as much as 25 feet lower during non-tourist hours than was permitted before 1950, exposing more debris at the base of the Falls.

By reference dated March 31, 1967, the governments of the United States and Canada requested the International Joint Commission, pursuant to Article IV of the Boundary Waters Treaty of 1909, to investigate and report upon measures necessary to preserve or enhance the beauty of the American Falls at Niagara. In 1967[14] The IJC established the American Falls International Board to undertake, through appropriate agencies in Canada and the United States, the necessary investigations and studies and to advise the Commission on all matters relevant to a report or reports under the above-cited reference. The Commission directed the Board to advise it as to the desirability of removing some or all of the talus collected at the base of the American Falls and feasible measures for effecting such removal; feasible and desirable measures to retard or prevent future erosion of the American Falls; any other measures which it consid-

FIGURE 11-65 American Falls Dewatered

ers desirable or necessary to preserve or enhance the beauty of the American Falls; and the allocation between the United States and Canada of the work and costs involved in undertaking any such measures.

From the examinations of the dewatered American Falls from June to November 1969 (Figure 11–65), some preliminary observations may be made as to the geologic character and condition of the Falls. Much compilation, correlation, and analysis must be done before completing the study, but it seems that the degree of undermining is less severe than had been anticipated.

There seem to be two types of failure mechanisms. In the 1931 rockfall, Rochester shale apparently was removed to a significant degree prior to failure. The failure occurred principally as a downdropping and the talus accumulated close to the area of the rockfall. In the July 1954 rockfall, apparently less undermining occurred prior to failure. That failure appears to have been a downward movement of the rock mass followed by a considerable amount of outward rotation, spreading the talus accumulation from the rockfall area to the Maid-of-the-Mist Pool. There is one large rock mass near Prospect Point that has become detached to a greater degree than previously realized. It is approximately 38,000 tons, half the size of the 1931 rockfall.

Flow over the American Falls is small compared to the Canadian Horseshoe Falls' flow. This smaller flow is not sufficient to cut through the lower rock strata, so that the masses of rock that fall from the crest of the Falls form a talus on a resistant lower shelf. As the talus accumulates, it partially protects the Rochester shale and apparently retards recession. The much greater flow over Horseshoe Falls cuts through the lower strata and forms a basin by the scouring effect of the fallen blocks in the turbulent water in the pool. As the blocks and fragments wear down, no significant talus accumulates at Horseshoe Falls and recession is greater.

To implement the 1950 Treaty concerning the use of the waters of the Niagara River, the United States and Canada constructed remedial works at the Falls and in the upper Niagara River. Their purposes were to reduce the erosional recession rate of the Canadian Horseshoe Falls, to provide a dependable flow of water over the Falls, and to control Chippawa-Grass Island Pool with the ability to meet promptly the permissible power diversions while assuring flows of 50,000 to 100,000 cubic feet per second over the Falls. The three major features of the remedial works were: Chippawa-Grass Island Pool control structure; excavation and fill on Goat Island flank of the Horseshoe Falls; and excavation and fill on Canadian flank of Horseshoe Falls.

The average flow over the American Falls today is 8,800 cfs, much less than in 1900 because much of the total river flow is now diverted for power production. The American Falls receives water around the open end of the control structure. Therefore, the discharge over these falls depends upon the level of the Chippawa-Grass Island Pool upstream. Since the control structure holds this level relatively constant, flow over the American Falls remains relatively constant even though the total flow over both Falls changes from 100,000 to 50,000 cfs. Actually the flow over the American Falls is slightly greater during periods of 50,000 cfs flow condition than at the 100,000 cfs condition.

By reference dated October 1970, the two governments directed the International Joint Commission to extend the study to include the American Falls flanks and also Terrapin Point of Horseshoe Falls. The problem of stabilization of these flank areas, and the question of public safety, will also be reported on by the American Falls International Board. The extended study is scheduled to be completed by December 1974.

Section 15

LAKE ONTARIO PROBLEMS AND NEEDS

15.1 General

Plan Area 5 (Lake Ontario) consists of three planning subareas (Figure 11–66).

15.2 Fluctuations of Lake Ontario

The average or normal elevation of the lake surface varies irregularly from year to year. During the course of each year, the surface is subject to a consistent seasonal rise and fall, lowest in winter, highest in summer. In the 110 years from 1860 to 1969 the difference between the highest (248.06 in June 1952) and the lowest (241.45 in November 1934) monthly mean stages was 6.61 feet. The greatest annual fluctuation as shown by the highest and the lowest monthly means of any year was 3.58 feet, and the least annual fluctuation was 0.69 foot. The maximum recorded short-period rise at Oswego, New York for the period 1933–1968 was 2.2 feet. This value was obtained by comparing the maximum instantaneous levels recorded each month with its monthly mean level.

Lake Ontario levels have been regulated since April 1960 in connection with the St. Lawrence Seaway and Power Projects, in accordance with the IJC's Orders of Approval dated October 29, 1952, and July 2, 1956, directly supervised by the International St. Lawrence River Board of Control. The Orders require that the Lake be regulated within a range of monthly mean stages from elevation 242.8 feet to elevation 246.8 feet (IGLD, 1955) during the navigation season.

During the winter, the level of Lake Ontario may drop below elevation 242.8 feet. Since 1960 is has dropped to a low elevation of 240.8 feet. The high level of 246.8 feet under regulation is 1.3 feet below the previous record high level of 248.1 feet, recorded in 1952. This reduction in high levels was to reduce the damage to shore property resulting from extreme lake stages. Regulation Plan 1958–D is described in detail in Section 6.

15.2.1 Flood Problems

Since the start of regulation in April 1960, Lake Ontario has had no major high water problems. High lake levels in 1951 and 1952 caused extensive damage and erosion along the shore. After this, U.S. property owners filed more than 530 claims. They claimed that Gut Dam (constructed by Canada in the Galop Island Rapids Section of the St. Lawrence River in the early 1900s) caused, or at least aggravated the high water. The courts have favored these claims. Although the structure was removed in 1953, this action shows the relationship between lake levels and damage, and the value of proper regulation of lake levels. The Lake Ontario Claims Tribunal, a three-member international arbitral tribunal appointed by the U.S. and Canada, has the final disposition of claims. Gut Dam is described in detail in Section 6.

15.2.2 New York State Barge Canal

The Niagara River system is the prime water supply for the New York State Barge Canal west of Lyons. The Court Street Dam in Rochester is operated to maintain the Genesee River crossing at canal navigation level and to insure an eastward canal flow of 375 cfs. Between Lyons and Three Rivers this flow is supplemented by releases from Seneca and Cayuga Lakes and runoff to the Seneca River basin. Figure 11–18 shows the canal system.

The water diverted into the canal enters Lake Ontario by four routes. It is spilled at Lockport, New York into Eighteenmile Creek; at Medina, New York into Oak Orchard Creek; at Rochester, New York into the Genesee River,[16] and flows into Lake Ontario by the Oswego River. An indeterminate amount is diverted at various places along the canal for irrigation purposes.

The western section of the Erie Canal has sufficient water supply available from Lake

TABLE 11-60 Data Stations, Planning Subarea 5.1

Reach of Shore	Weather Station	Water Level Station	Reach No.
Niagara River to Hamlin Beach, N.Y.	Rochester, N.Y.	Rochester, N.Y.	2001
Hamlin Beach, N.Y. to Rochester, N.Y.	Rochester, N.Y.	Rochester, N.Y.	2002

TABLE 11-61 Data Stations, Planning Subarea 5.2

Reach of Shore	Weather Station	Water Level Station	Reach No.
Rochester, N.Y. to Port Ontario, N.Y.	Oswego, N.Y.	Oswego, N.Y.	2003
Port Ontario, N.Y. to Stony Creek, N.Y.	Oswego, N.Y.	Oswego, N.Y.	2004

Erie by way of the Niagara River. This is estimated at 1,100 cfs per month during the navigation season, and considered to be the hydraulic capacity of this segment of the canal system as it is presently operated. Any future plans to divert more water from the Niagara River at Tonawanda, New York would require a detailed investigation to determine whether such increases could be passed without damage.

15.3 Planning Subarea 5.1

Planning Subarea 5.1 comprises the Niagara-Orleans Complex and Genesee River drainage areas (Figure 11-67).

15.3.1 General

Ultimate storm water level data for Planning Subarea 5.1 were computed using data from Table 11-60.

In the first 50 miles east of Niagara River, the shoreline of Lake Ontario has a steep clay bluff of varying height, with some short narrow beaches footing the bluff. In the next segment of shoreline the shore is much lower, with only short disconnected clay bluffs and numerous marshy areas behind barrier beaches in the vicinity of Rochester, New York. Serious shore erosion and some inundation problems exist throughout the shoreline of Planning Subarea 5.1.

15.3.2 Rochester Harbor

Rochester Harbor is at the mouth of the Genesee River seven miles north of the main business district of the City of Rochester. The river is navigable for six miles above the mouth with controlling depths of 21 feet for the first three miles, 13 feet for an additional two miles, and 11 feet to the first of a group of dams just above the Ridge Street Bridge. There is no navigable connection between the lower portion of the Genesee River and the New York State Barge Canal, which joins the river 11 miles upstream from the Lake. There is a fall in the surface elevation of the river of more than 260 feet between the Rochester Terminal of the New York State Barge Canal System and the head of navigation of the lower portions of the river below the dams.

15.4 Planning Subarea 5.2

Planning Subarea 5.2 consists of the following drainage areas: the Wayne-Cayuga Complex, the Oswego River, and the Salmon River Complex (Figure 11-68)

15.4.1 General

Ultimate storm water level data for Planning Subarea 5.2 were computed using data from Table 11-61.

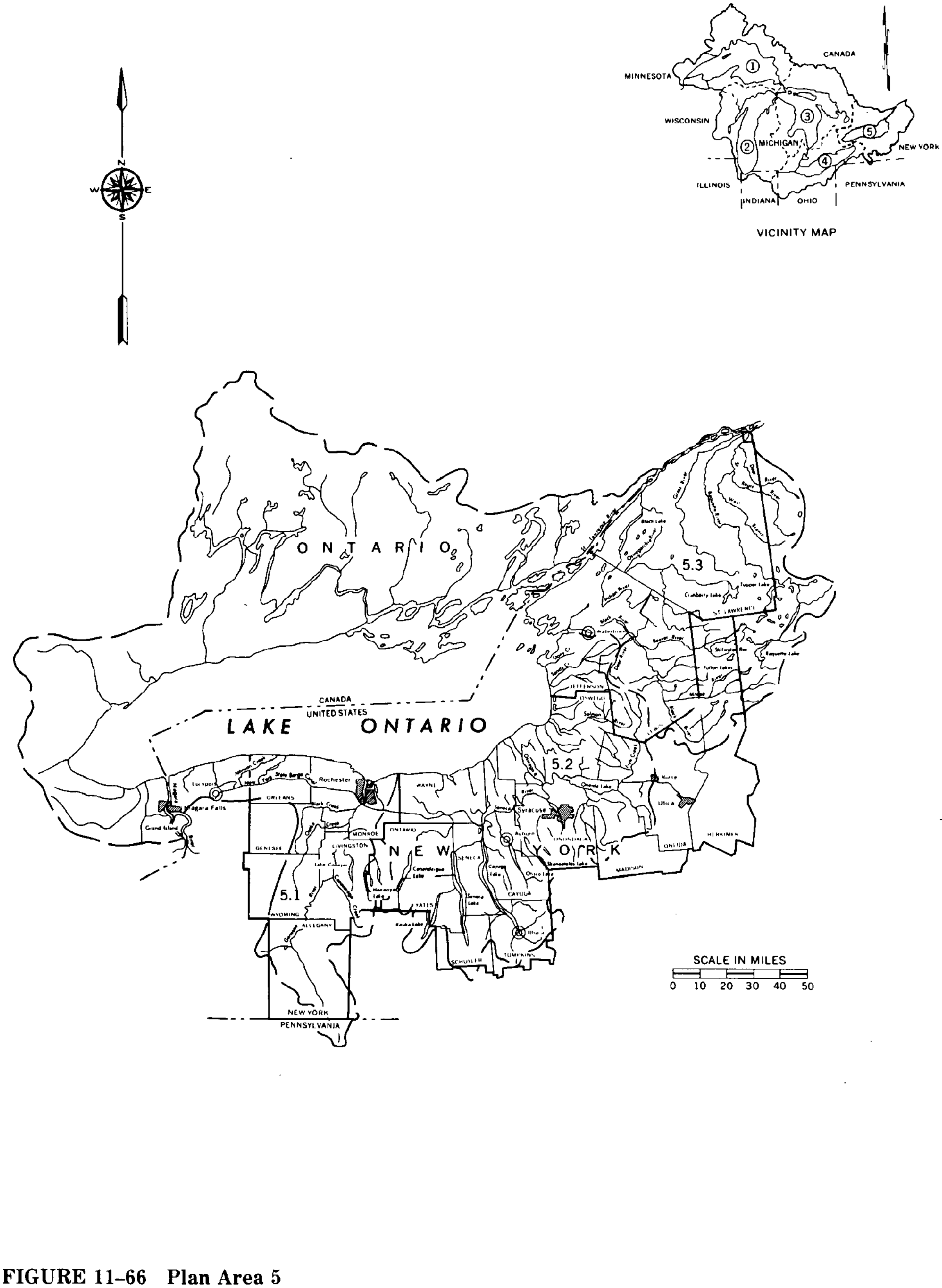


FIGURE 11-66 Plan Area 5

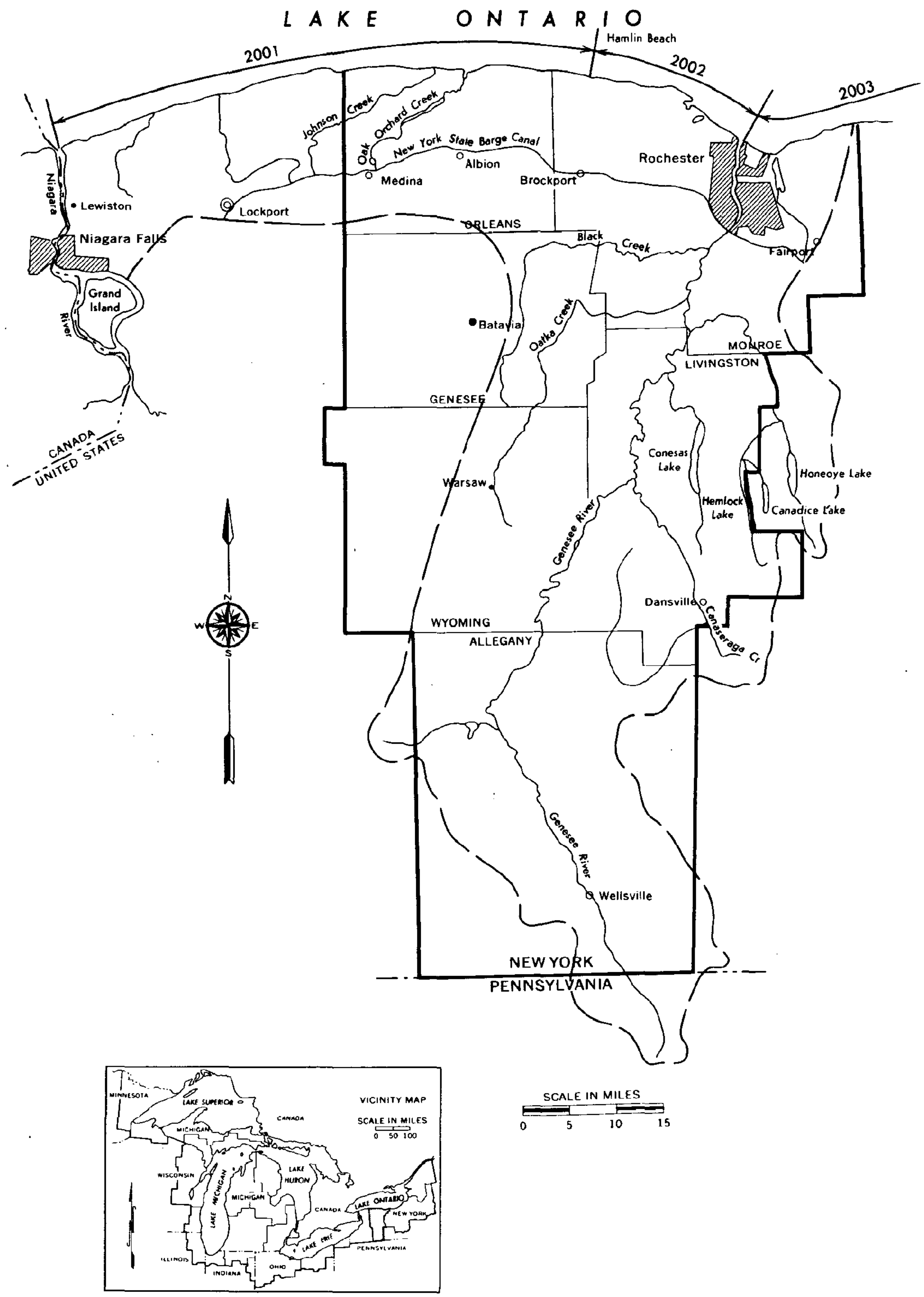
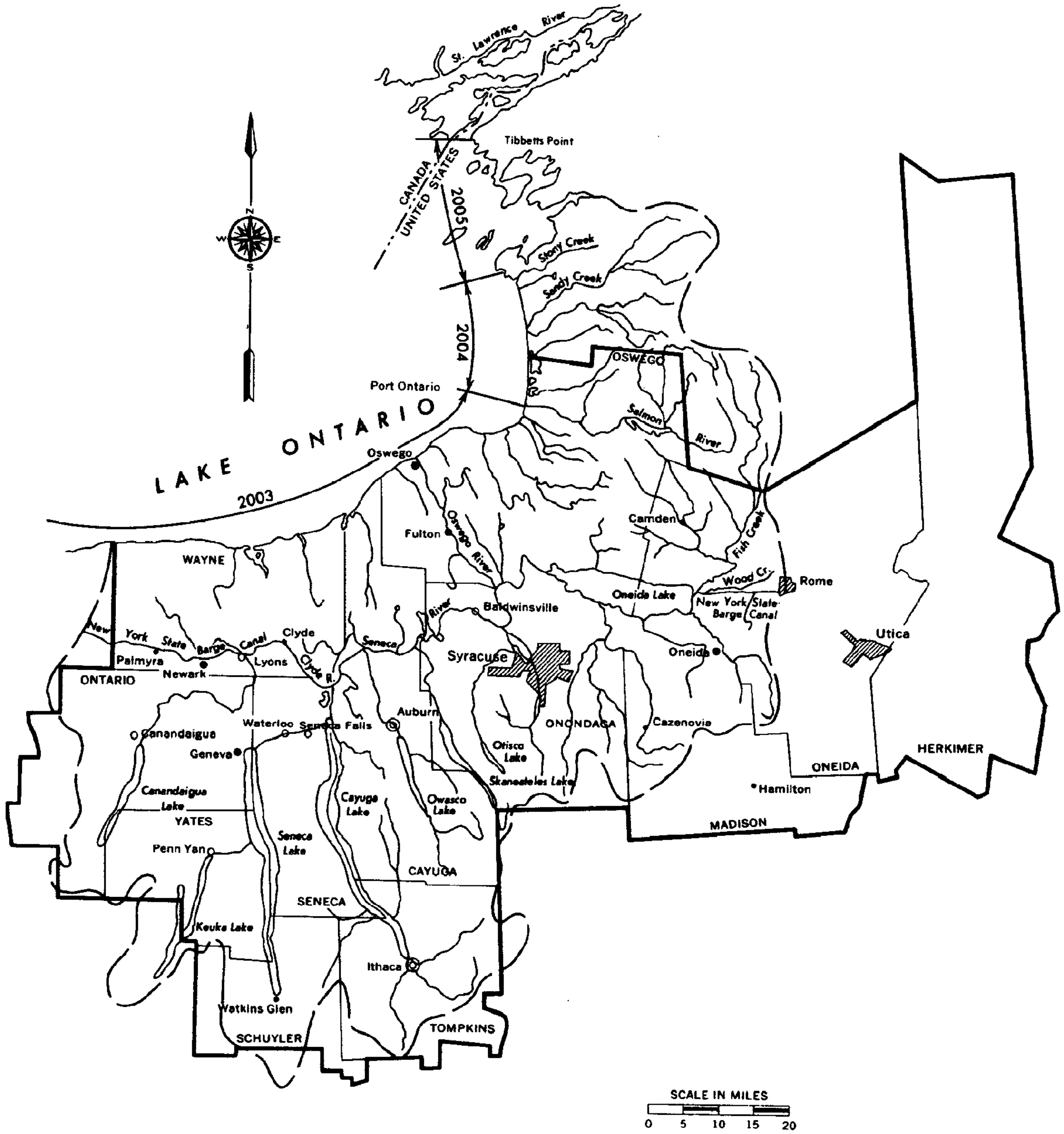


FIGURE 11–67 Planning Subarea 5.1



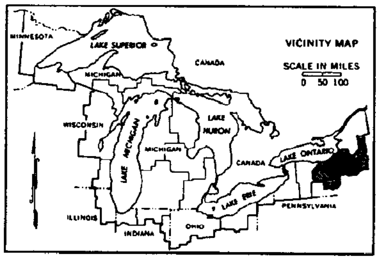


FIGURE 11-68 Planning Subarea 5.2

The regulation of Lake Ontario as part of the operation of the St. Lawrence Seaway and Power Project has decreased the range of lake level fluctuations. High lake levels are reduced by one-half foot, although bank and shore erosion continues throughout the planning subarea along Lake Ontario. East of Sodus Bay, homes will soon be lost because of extensive erosion. Other erosion problems exist at Selkirk Shores State Park, Fair Haven Beach State Park, and near Sterling Creek outlet. Lake level data and ultimate stormwater level data will be useful in further studies for improvements in these areas.

Ice jams at the mouths of streams are not a problem along the shores of Lake Ontario in Planning Subarea 5.2. The ice build-up that does occur along the shore dampens the wave action and protects the shoreline.

Ten miles northeast of Oswego, nuclear power plants will provide power for upstate New York through three 345,000-volt transmission connections. The Nine Mile Plant, opened by the Niagara Mohawk Power Corporation in 1969, has a gross capacity of 642,000 kW. The Fitzpatrick Plant, under construction by PASNY, was expected to begin operation in 1974 at 850,000 kW. A second plant is planned at Nine Mile for 1978. These plants will increase consumptive water loss for Lake Ontario. Large lakes and reservoirs in the Oswego basin affect Lake Ontario elevation fluctuations, especially during spring thaws.

15.4.2 Navigation Facilities

Great Sodus Bay and Oswego Harbors are deep-draft navigation harbors protected by piers and breakwaters. Port Bay, Little Sodus Bay, Port Ontario, and Sackets Harbor are small-boat harbors of varying depths. Improvements for Port Bay and Port Ontario have not been authorized. Only Little Sodus Bay has an active Federal project. As small-boat interest in these areas grows, lake level and wave data will be required for these harbors. The overflow of boating enthusiasts from the inland waterways will increase recreational boating around Port Ontario.

The introduction of coho salmon in the Salmon River has also attracted fishermen. Little Sodus Bay Harbor has a growth problem which also causes problems with all recreational water uses in the shallow water areas of Cayuga, Seneca, and Oneida Lakes.

15.4.3 Water Level Datums

There is an additional problem in Planning Subarea 5.2 that must be considered in any watershed study. Several datum planes are used on Lake Ontario, so that care must be taken to base all elevations in one study on the same datum plane. Examples of the differences between planes: International Great Lakes Datum (1955) at Oswego +1.22 = U.S.C.G.S. Datum; at Lock Number 1, north end of Cayuga Lake, U.S.C.G.S. Datum + 1.30 = Barge Canal Datum; at Balwinsville, U.S.C.G.S. Datum +1.05 = Barge Canal Datum.

15.5 Planning Subarea 5.3

Planning Subarea 5.3 consists of the following drainage areas: Black River, Perch River Complex, Oswegatchie River, and Grass-Raquette-St. Regis Complex (Figure 11–69).

15.5.1 General

Ultimate storm water level data for Planning Subarea 5.3 were computed utilizing data from Table 11–62.

The regulation of Lake Ontario has decreased the range of fluctuation of lake levels and has reduced high levels by about one-half foot. Erosion, with the exception of some sandy shoreline areas, is not a serious problem in Planning Subarea 5.3. The major portion of the shoreline and channel is composed of bedrock, ledgerock, and gravel.

The revised St. Lawrence River Navigation Regulations, dated October 16, 1970, establish more control over vessel speeds, and provide St. Lawrence River beaches more protection over a much larger area.

During 1969 the levels of all the Great Lakes were above their long-term average elevations. Lake Ontario had well above average levels during most of the summer recreation season. With high levels, higher outflows were required at the Moses-Saunders Powerhouse, resulting in a lowering of Lake St. Lawrence to a degree never experienced before by riparian users. Many recreational boaters complained. Such low levels result from the hydraulic necessity of the steep slopes between Lake Ontario and the powerhouse to permit the discharge of the high outflows from Lake Ontario. This situation will recur with above-

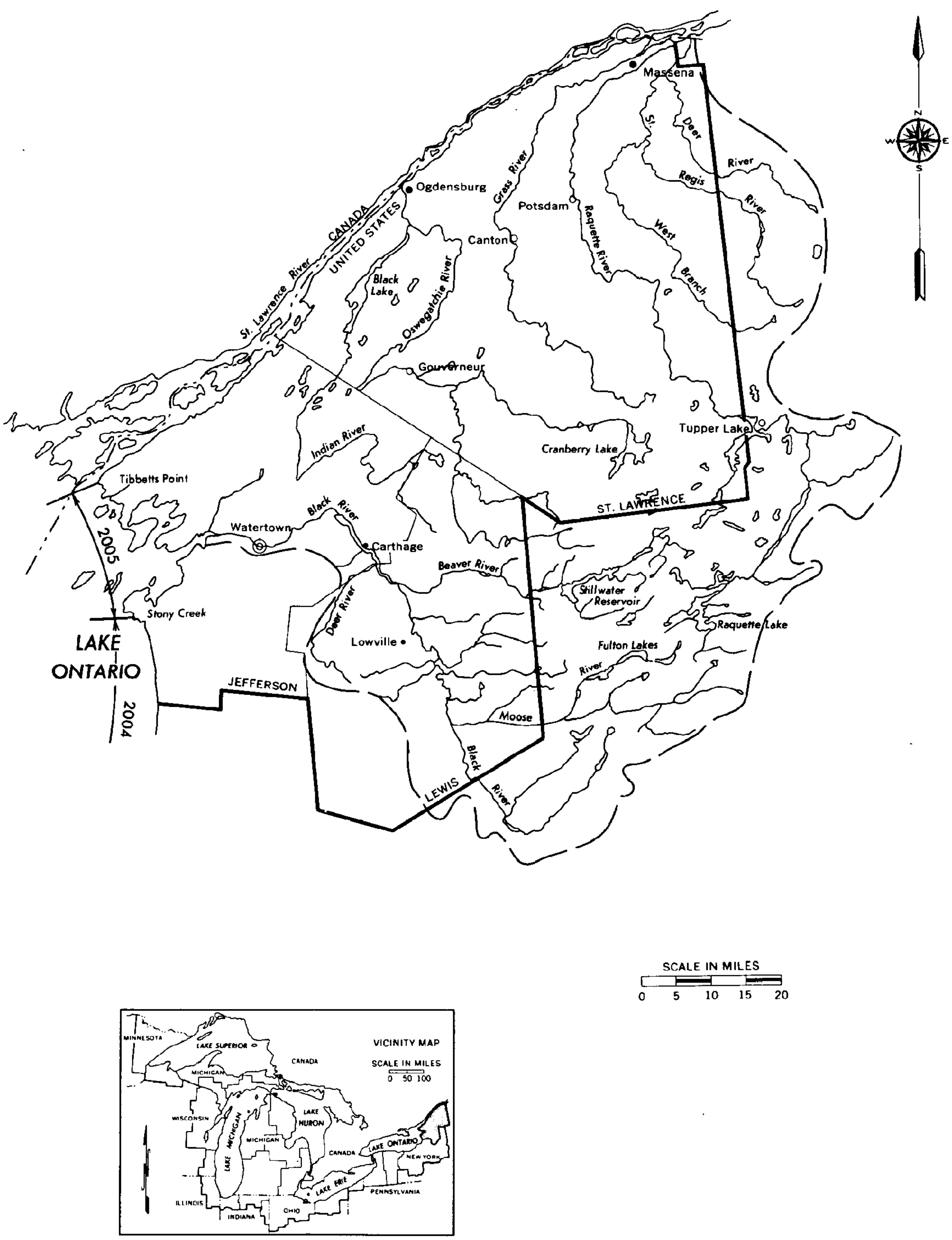


FIGURE 11-69 Planning Subarea 5.3

TABLE 11-62 Data Stations, Planning Subarea 5.3

Reach of Shore	Weather Station	Water Level Station	Reach No.
Port Ontario, N.Y. to Stony Creek, N.Y.	Oswego, N.Y.	Oswego, N.Y.	2004
Stony Creek, N.Y. to Tibbetts Point, N.Y.	Watertown, N.Y.	Oswego, N.Y.	2005

normal lake levels. The reverse condition, high levels on Lake St. Lawrence, exists when low outflows are required at the powerhouse.

The International St. Lawrence River Board of Control has investigated the situation, concluding that discretionary deviations from computed outflow might be used in certain years to improve the low levels of Lake St. Lawrence during the recreational season. These deviations can be applied only infrequently, as they would not be significant improvements and may be detrimental to other interests.

There are many small capacity hydroelectric power plants located on tributaries in Planning Subarea 5.3, most with medium-to-high head but operating primarily on a run-of-the-river basis with only small, brief storage. The International Moses-Saunders Powerhouse on the St. Lawrence River has an installed capacity of 1,824,000 kW. Regulation of Lake Ontario is carried out by the computed weekly discharges from this powerhouse. To carry out successful power operation during the winter, approximately four miles of ice booms have been used upstream from the power dam. The booms reduce ice jamming and help maintain uninterrupted flows. A problem that would have to be solved in order to extend the winter navigation season on the International Rapids Section of the St. Lawrence River would be developing a means of maintaining a stable ice condition on the river. The power entities (Power Authority of the State of New York and Hydro Electric Power Commission of Ontario) have the responsibility for installing and maintaining the six ice booms. This includes any shoreline damages that may be caused by the installed ice booms or their operations. Lake levels and flow data will be extremely important in studies being made for the extension of the St. Lawrence Seaway winter navigation season.

Lake fluctuations affect operations of harbors and navigation facilities in Planning Subarea 5.3. The harbors at Cape Vincent, Ogdensburg, and Morristown have project depths of 10 feet. These harbors have hard channel bottoms so that level fluctuations are important. The combination of levels of Lake Ontario and flows in the St. Lawrence River establish the navigation depths and power production.

Because of the International St. Lawrence Power Development, diversion of water into or out of the Great Lakes can have a measurable effect on the region's power production. A diversion of 1,000 cfs can mean the annual production or loss of $140,000 of power beside the value of power capacity and the industrial production involved.

15.5.2 IJC Order of Approval—Raisin River Diversion

The Raisin River lies just north of the St. Lawrence River in the Province of Ontario. It discharges into the St. Lawrence River near the Village of Lancaster downstream from the St. Lawrence Power Development. In summer its flows are low, sluggish, and intermittent.

The Raisin Region Conservation Authority is a corporate body established under the Conservation Authorities Act of the Province of Ontario to carry out conservation programs in the Raisin River watershed and adjoining areas under its jurisdiction. This Authority applied to the IJC through the Canadian government for permission to divert water from Lake St. Lawrence in the St. Lawrence River to the Raisin River watershed.

The IJC issued an Order of Approval on December 31, 1968, allowing the diversion of approximately 25 cfs from Lake St. Lawrence into the Raisin River watershed for 100 days, to augment the natural low summer flows in the Raisin River, for a period not to exceed four years. This provided a reliable water source for farms and villages, an improved environment for fish and wildlife, and an increase of the Raisin River's recreational and aesthetic values. The diversion would be made at two Lake St. Lawrence locations, one near the Village of Long Sault and the other two and one-half miles west of there. The diverted water would be returned to the St. Lawrence River at the mouth of the Raisin River, near the Village of Lancaster.

At the IJC hearing on this matter, testimony was presented describing conditions in the Raisin River and a tributary, the South Raisin River, and the purpose of the proposed diversion of water from the St. Lawrence River. Due to the flatness of the Raisin River watershed, there are no feasible reservoir sites where water might be impounded in the spring to augment the low summer flows. The Counsel for the Hydro Electric Power Commission of Ontario stated that the Commission agreed to the proposed diversion, provided that the applicant reimbursed PASNY for the value of the hydroelectric power that the diverted water would have generated had it not bypassed the Robert H. Saunders Generating Station downstream on the St. Lawrence.

This diversion is a minor amount of the flow of the St. Lawrence River. However, the precedent established by this Order of Approval may well carry into other diversions of this nature. In December 1970 the International Joint Commission approved the plans and specifications for the diversion works to pass the requisite amount of water from Lake St. Lawrence into the Raisin River.

Section 16

DATA AND RESEARCH NEEDS

16.1 General

The relationship of many of the factors that affect the fluctuation of lake levels are imperfectly understood. This can be improved by an active physical research program paralleling and extending beyond the engineering studies currently in progress for the International Joint Commission's study. Important factors include precipitation, evaporation, winds, barometric pressure differentials, and ice. Precipitation on the Great Lakes and on their tributary land areas is the source of all the water entering the Lakes, whereas evaporation removes about two-thirds of this water from the Basin. Variations of these two factors largely cause the long-term water level fluctuations. Wind and barometric pressure differentials over the Lakes and ice on them and in their outflow rivers cause short-term fluctuations.

16.2 Progress on Needs

Researchers have filled several needs for levels and flows data recently or are presently filling them. The necessary detailed hydrographic surveys on the St. Clair River have been completed to provide physical data required to develop a hydraulic mathematical model. Investigators accomplished the necessary field collection and office compilation as part of the present IJC study.

As a joint Canadian-U.S. effort, a Leading Edge (acoustical) flow meter was installed in the Niagara River near the International Railroad Bridge at Buffalo, New York-Fort Erie, Ontario. The flow meter, which was installed by the Westinghouse Company in 1971, has not been functioning satisfactorily. Efforts to improve its operation are still under way. The continuously-monitoring flow meter may bring improved knowledge of Niagara River discharges. This could be of value to the power operations at Niagara Falls, New York.

16.2.1 Hydraulic Investigations

A study to determine the effect of vessel squat in constricted reaches of connecting channels would be valuable for determining safe vessel speeds under various loads. With large vessels being constructed, this factor is becoming an increasingly important hydraulic consideration for deep-draft navigation. An area of study might be the Livingston channel of the lower Detroit River, with an estimated cost of $20,000.

The compilation and development of charts showing velocities and direction of current in connecting channels would provide vital information for commercial and recreational navigators. This information will also help to solve sewage, pollution, and water supply problems. Estimated cost for conducting the necessary field work on the connecting channels and compilation is $75,000.

A study to determine the feasibility of maintaining an index meter in the Detroit River during the winter period would be of value. Experiments during recent discharge measurements taken on the Detroit River indicate an installation below the water surface could measure winter flows and verify application of open-water discharge equations. Such a feasibility study is estimated to cost $15,000.

The New York State Barge Canal diversion at Tonawanda, New York, should be verified. Reported amounts of the diversion from the Niagara River through the canal are based on 1916 field discharge data. Updated field measurements would also be required to determine the maximum diversion capacity of the New York State Barge Canal. This work would cost approximately $20,000.

There are a number of other short-term requirements that come up from time to time, dealing essentially with hydraulic problems on the connecting channels of the Great Lakes, for which no specific funds are available. To implement the projects and standard periodic discharge measurements of the connecting channels not itemized, the Corps of Engineers estimates annual work cost at $50,000. Each investigation will require coordination of field activities with the Water Survey of Canada.

16.2.2 Hydrology Studies

Fluctuations in Great Lakes levels are intimately related to variations in precipitation. Much further physical research is required to determine this relationship.

Some other short-term problems requiring investigation are:

(1) comparison of instruments and methods used in Canada and the U.S. for measuring rain and snow

(2) studies to establish the best (and minimum) size of precipitation networks required for regulation studies and lake level forecasts

(3) studies to establish the representativeness of overland precipitation measurements for overwater areas

(4) relative effect of seasonal (or monthly) precipitation on lake levels. Does one inch of precipitation affect lake level to the same extent in June as in November?

(5) the contribution of snowmelt to lake levels. What sequence of meteorological events produced maximum and minimum variations in levels due to snowmelt?

Further discussions on several of these items are in Appendix 4, *Limnology of Lakes and Embayments.*

16.3 Long-Term Requirements

Long-term data needs require extensive investigation of time, manpower, and funds. Many of these needs are associated with requirements of ongoing data collection efforts required to assess environmental changes. It was mentioned in Section 10 that increased urbanization is affecting the local climate and meteorology in some plan areas. The impact of such long trends must be considered in light of how they affect Great Lakes water supplies. Because of the large water surface in the Great Lakes, data cannot be collected directly on a year-around basis, but must be obtained from land-based stations. There is a need for research into the relationship between the data overland and corresponding data over the lake surfaces to make the over-water data more reliable. Other research needs are described in following subsections.

16.3.1 Precipitation

One of the most important derived-supply factors is the amount of precipitation directly on the lake surface. The Lake Survey Center, NOAA, publishes monthly precipitation data, overwater, for each Lake. These data are derived by averaging precipitation measured at land stations. Limited simultaneous observations of precipitation overwater as measured by tiny island stations and overland by stations not far from the shoreline have indicated equal annual amounts, with a difference in the seasonal distribution. The overwater precipitation for a 10-year period was approximately 9 percent less in warm weather and 9 percent more in cold weather than at nearby land stations. Before reliable month-by-month data will be available for precipitation on the Lakes, more field observations must be made to better establish the relationship with precipitation at land stations. The analytical methods should be improved to correlate those data. Further discussions on this subject are in Appendix 4, *Limnology of Lakes and Embayments*.

16.3.2 Wind

Winds cause shore damage through waves, currents, shore erosion, and littoral drift, as well as short-term variations in water levels through set-ups and seiches. Overlake winds are stronger than corresponding overland winds due to reduced frictional effects. However, overlake to overland wind ratios vary from month to month with changes in air mass stability created by differences between air and water temperature. Further studies are needed to confirm recent findings and to evaluate the wind field over each Lake from the known wind field overland, to obtain better estimates of hourly winds over the water to determine deepwater wave characteristics and the resulting maximum storm water levels, and to obtain better wind data to improve estimates of evaporation from the Lakes on a month-by-month basis. New meteorological stations in deficient locations could provide them. As pointed out in Section 10, a minimum meteorological network station should be established coinciding with the present water-level gaging network. Overlake air temperature and relative humidity data could also be improved. Further discussions on this subject are in Appendix 4, *Limnology of Lakes and Embayments*.

16.3.3 Runoff

Runoff from large areas, especially near the shores of the Great Lakes, is not gaged and probably will not be in the foreseeable future because of the physical problems of gaging at the mouths of tributary streams. Research is required to improve estimates of runoff from ungaged areas for use in obtaining month-by-month total runoff into a Lake from its tributary basin.

16.3.4 Evaporation

Twice as much water is being lost through evaporation from the Great Lakes Basin as flows out the St. Lawrence River. While recent advances in understanding this phenomenon are encouraging, there are still many areas requiring more study.

Some objectives are to:

(1) establish reliable estimates of average annual and monthly evaporation from each Lake (only Lakes Ontario and Erie appear fairly reliable)

(2) improve estimates of month-to-month and year-to-year evaporation from Lakes Ontario and Erie and extend them to other Lakes

(3) develop a technique and instrumentation network to evaluate quickly monthly (or weekly) evaporation from regularly observed parameters

16.3.5 Great Lakes Ice

Each of the Great Lakes is at least partially ice-covered for three to five months of the year. This ice affects lake levels by reducing outflow, evaporation, and local precipitation. Ice also drastically shortens the navigation season and creates problems in power production. Information is needed on the behavior of ice cover in the Lakes and connecting rivers under changing flow conditions, and on the formation of ice jams, in order to plan for optimum outflow patterns during the winter months. Forecasting the formation of ice cover will help to extend the navigation season in the connecting channels, and possibly in the Lakes. Further discussion on this subject is found in Appendix 4, *Limnology of Lakes and Embayments*.

To facilitate winter navigation on the Great Lakes, it is necessary to find some means of stabilizing the ice area and preventing the wind from breaking it up, while maintaining safe open channels for the passage of commercial vessels. The Lake Huron outlet critically needs ice-area stabilization. Data needs and additional research investigations required for determining the practicability of winter navigation on the Great Lakes are:

(1) detailed study of the formation, movement, breakup and decay of the ice cover in the lower Lake Huron to Lake Erie reach, particularly the outlet of Lake Huron. This would include all factors affecting the ice bridge, and its characteristics. Other critical areas to be studied would include Whitefish Bay-St. Marys River, Straits of Mackinac, and the St. Lawrence River.

(2) collection of all necessary hydraulic data in order to establish optimum location of ice stabilization devices in Lakes Huron and St. Clair, also St. Marys and St. Lawrence Rivers. Studies using hydraulic models should be considered.

(3) careful evaluation of present techniques of establishing ice control as they apply to the problems faced in these studies. This may also require some experimental work.

(4) a careful study of possible effects on Great Lakes levels caused by anticipated changes in ice retardation brought about by keeping channels open for navigation

Appendix C9, *Commercial Navigation*, describes operational problems and economic investigations needed to determine whether the winter navigation period should be extended.

16.3.6 Water Characteristics

It has been suggested that regulation may improve water quality in some of the Lakes, especially Lake Erie. This would require detailed knowledge of variations of water characteristics by time and location. Water inflow to a Lake might be scheduled when the quality of the upstream Lake is high in comparison to that in the lower Lake. Knowledge of vertical and horizontal water diffusion factors and of the effect of Niagara Falls on the water of Lake Ontario is also needed. Permanent stations would be required in the Lakes to record these water characteristics and their associated factors. These stations, when calibrated with the Lake proper, would indicate the long-term changes in water releases from the Lakes for the improvement of water quality.

16.3.7 Water-Level Forecasting

The various research needs suggested under precipitation, evaporation, wind, and ice should be coordinated to evaluate their effect on lake levels. These needs should be evaluated:

(1) effects of precipitation and evaporation on lake levels over different periods: day-to-day, month-to-month, year-to-year, and longer. A study of lag periods between precipitation and lake levels will help to establish a procedure, based on physical and statistical analyses, to predict brief and lengthy variations

(2) the effect of wind and barometric pressure on lake levels through wind set-up and seiches in order to forecast short-period water level changes at regulatory structures

(3) the effect of ice cover in the Lakes and in connecting channels on the seasonal variations of lake levels

(4) development of reliable weather forecasts for periods from 30 days to 6 months on an individual Lake basin in order to refine water-level forecasts

16.3.8 Conclusion

It is expected that the intensive research efforts being made in conjunction with the wealth of data to be collected during the International Field Year on the Great Lakes will help provide for some of the long-term needs as well as determine future research requirements on Lake Ontario and the other Great Lakes. For several years the joint Canadian and United States effort has been preparing for a full-year data collection effort that was initiated in April 1972. This program is largely physical in nature encompassing a number of related and international studies on water balance, meteorology, and circulation in Lake Ontario.

The *Limnological Systems Analysis of the Great Lakes: Phase I* was prepared by a consultant for the Great Lakes Basin Commission in March 1973 to provide insight into the complex interrelationship among the various Lake environment subsystems. A proposed Phase II study should improve knowledge of the relationship of lake levels to the lake environment.

Section 17

MANAGEMENT AND FUTURE DEMANDS

17.1 General

There are a number of established IJC control and technical boards dealing with various aspects of Great Lakes levels and flows. The International Joint Commission, in fulfilling the purposes of the Boundary Waters Treaty of 1909[50] has wide-ranging responsibilities. The first is to approve or disapprove all proposals for use, obstruction, or diversion of boundary waters on either side of the boundary which would affect boundary level or flow on the other side. Projects may be brought before the IJC by application of public agencies, private corporations, or individuals. Examples in the Great Lakes system include the regulatory works in Sault Ste. Marie and those on the St. Lawrence River. The applicant has to furnish all necessary information and data.

The second general responsibility of the IJC is to investigate and make recommendations on specific problems of either or both governments. It is under this provision of the treaty that requests or references by the two governments have been made on such subjects as regulation of the Great Lakes levels, water pollution, and preservation of the American Falls at Niagara. In this case, the Commission appoints an international technical board to make a thorough investigation of the facts involved and file a written report. The Commission holds public hearings, normally one in each country in the areas affected, at which any person may comment on the findings and recommendations. Public hearings may also be held before an investigation to determine problems and areas affected.

17.2 International Joint Commission Boards

There are three control boards and two technical boards pertaining to management or investigation of Great Lakes levels and flows. These boards have continuing responsibilities as prescribed by the IJC.

17.2.1 International Lake Superior Board of Control

This two-member Board (Figure 11–70) is responsible for regulating Lake Superior water levels and outflows. The Board prescribes the necessary monthly gate settings at Sault Ste. Marie, Michigan, and Sault Ste. Marie, Ontario, depending on the requirements of the approved regulation plan and consideration of the water-level and supply situation prevailing throughout the Superior basin. The Board meets at least annually at Sault Ste. Marie to inspect the condition and maintenance program of the control works.

17.2.2 International Niagara Board of Control

This four-member Board (Figure 11–70) is responsible for supervising the construction, operation, and maintenance of remedial works, described earlier, provided in the Niagara River under the 1950 Treaty. These works allow maximum power diversions around the Falls while maintaining Lake Erie and Niagara River water levels for navigation and shore property interests, and Treaty flows over the Falls for scenic purposes. These works also include an ice boom at the outlet of Lake Erie. The District Engineer, Buffalo District, Corps of Engineers, is the chairman of the U.S. section of the Working Committee.

An agency identification legend follows for international boards and committees shown in Figures 11–70 to 11–74.

17.2.3 International St. Lawrence River Board of Control

This eight-member Board (Figure 11–70) is responsible for supervising the operation and maintenance of the St. Lawrence Seaway and Power Project and coordinating the regulation of Lake Ontario water levels and outflows. The Board is advised concerning op-

Agency Identification Legend

UNITED STATES

BFLO DIST—Buffalo District, Corps of Engineers
BSF&W—Bureau of Sport Fisheries and Wildlife, U.S. Department of Interior
BU. OF MINES—Bureau of Mines, U.S. Department of Interior
DEPT. OF COMMERCE—Department of Commerce
DEPT. OF INTERIOR—Department of the Interior
DETROIT DIST—Detroit District, Corps of Engineers
EPA—Environmental Protection Agency
FPC—Federal Power Commission
GLBC—Great Lakes Basin Commission
GLC—Great Lakes Commission
IJC—International Joint Commission
LSC-NOAA—Lake Survey Center, National Oceanic and Atmospheric Administration
MARAD—Maritime Administration, Department of Commerce
NCD—North Central Division, Corps of Engineers
NFSPC—Niagara Frontier State Park Commission
NWS-NOAA—National Weather Service, National Oceanic and Atmospheric Administration
OCE—Office, Chief of Engineers, Corps of Engineers
PASNY—Power Authority of the State of New York
SLSDC—St. Lawrence Seaway Development Corporation
UNIV. OF CALIF.—University of California, Berkeley

CANADA

DEPT. OF FISHERIES—Department of Fisheries
DPW—Department of Public Works
ENV. CANADA—Department of Environment, Canada
HEPCO—Hydroelectric Power Commission of Ontario
HYDRO-QUEBEC—Hydroelectric Power Commission of Quebec
KC&O-ARC—Kane, Carruth & O'Brien, Landscape Architects
MOT—Ministry of Transport
NPC—Niagara Parks Commission
ODLF—Ontario Department of Lands and Forests
PROV. OF ONTARIO—Province of Ontario
PROV. OF QUEBEC—Province of Quebec
UNIV. OF TORONTO—University of Toronto

INTERNATIONAL LAKE SUPERIOR BOARD OF CONTROL

U.S. - Division Engineer, NCD
S. H. Fonda, Jr., NCD (Secretary)
CANADA - R. H. Clark, ENV. CANADA
N. P. Persoage, ENV. CANADA (Secretary)

INTERNATIONAL NIAGARA BOARD OF CONTROL

U.S. - *Division Engineer, NCD
D. Brown, FPC
S. H. Fonda, NCD (Secretary)
CANADA - *R. H. Clark, ENV. CANADA
C. K. Hurst, DPW
N. P. Persoage, ENV. CANADA (Secretary)

WORKING COMMITTEE

U.S. - *District Engineer, Buffalo
W. H. S. Diehl, FPC
CANADA - *B. E. Russell, ENV. CANADA
K. A. Rowsell, DPW

INTERNATIONAL ST. LAWRENCE RIVER BOARD OF CONTROL

U.S. - *Division Engineer, NCD
D. Brown, FPC
R. D. Conner, PASNY
F. F. Snyder, OCE (Retired)
S. H. Fonda, NCD (Secretary)
CANADA - *D. M. Ripley, MOT
R. H. Clark, ENV. CANADA
J. B. Bryce, HEPCO
Y. De Guise, HYDRO-QUEBEC
C. J. R. Lawrie, MOT (Secretary)

WORKING COMMITTEE

U.S. - *District Engineer, Buffalo District
S. H. Fonda, NCD
R. D. Conner, PASNY
J. H. Spellman, FPC
CANADA - *D. F. Witherspoon, ENV. CANADA
R. H. Smith, MOT
R. A. Walker, HEPCO
F. Santerre, HYDRO-QUEBEC

ST. LAWRENCE RIVER OPERATIONS ADVISORY GROUP

D. M. Foulds, HEPCO
R. D. Conner, PASNY
F. Santerre, HYDRO-QUEBEC
J. B. Adams, SLSDC
R. H. Smith, MOT

*Chairman

FIGURE 11–70 International Boards of Control

eration of the projects by an Operations Advisory Group (Figure 11–70) composed of representatives of several interests on the river. The District Engineer, Buffalo District, Corps of Engineers, is chairman of the U.S. section of the Board's Working Committee. The Chief, Hydraulics Branch, Engineering Division, Buffalo District, Corps of Engineers, is the Board's U.S. representative in coordinating weekly outflow from the project. Board meetings are normally held semi-annually at the time of the IJC regular meetings and also as required to resolve operating problems.

17.2.4 International Great Lakes Levels Board

The International Great Lakes Levels Board (Figure 11–71) was appointed in accordance with a reference from the two governments to the International Joint Commission dated October 7, 1964. The reference requested that the Commission study the various factors which affect the fluctuation of Great Lakes water levels and determine the practicality of further regulation of the Lakes. The Board appointed a seven-member Working Committee to prepare the data and studies pertinent to the Board's report.

The Working Committee appointed three subcommittees to determine the effect of regulation on shore property, power, and navigation interests. A fourth subcommittee is to develop necessary regulation plans, a fifth is to carry out the necessary studies of the regulatory works required for various regulation plans, and a sixth is to prepare the necessary guidelines for and supervise the preparation of the complex report to the Commission. As can be seen from Figure 11–71, the study represents pertinent U.S. and Canadian Federal and Provincial agencies at all levels. Because of the number of States in the Great Lakes Basin, there is no direct State membership on the Board or its committees. However, through correspondence with the Governors and State representatives at subcommittee meetings, the States have been fully advised and involved in the studies to the extent that they wish. Details of this study have been described in Sections 7 and 10.

17.2.5 American Falls International Board

This four-member Board (Figure 17–72) was appointed in accordance with a reference from the two governments to the International Joint Commission dated March 31, 1967, requesting that the Commission investigate and report upon measures necessary to preserve and enhance the beauty of the American Falls at Niagara. The Division Engineer, North Central Division, Corps of Engineers, is the U.S. chairman of the Board. The Canadian chairman is J. D. McLeod, Senior Engineer, Department of Environment, Canada. The other members of the Board from each country are well-known landscape architects. The U.S. member is Garrett Eckbo, Dean of Landscape Architecture, University of California at Berkeley. The Canadian member is H. S. M. Carver, Central Mortgage and Housing Corporation (retired). The Commission selected these men because of the inherent aesthetic aspects of the American Falls study.

Early in 1970, the Board had information from local interests concerning the stability of several areas of the Niagara Gorge wall near the American Falls. The International Joint Commission was asked to advise on the limits of the Board's responsibility. The stability of a large portion of the Prospect Point area as well as Terrapin Point and Luna Island areas is doubtful. Terrapin Point is on the Goat Island flank of the Canadian Horseshoe Falls, whereas the Prospect Point and Luna Island areas adjoin the American Falls. The two governments issued a new reference dated October 1, and October 5, 1970, requesting that the IJC expand the American Falls study to include these problem areas and examine the subject of public safety.

An Interim Report to the IJC on progress of the study was released by the Commission in early 1972. This presented the historical background of the problems and a discussion of aesthetic factors and physical conditions which must be considered in reaching a solution. It explored the range of options for preserving or enhancing the beauty of the American Falls and for securing the safety of the viewing public, and grouped them into several broad alternative courses of action. The Board's final report to the International Joint Commission is scheduled to be completed in June 1974. The appendixes to the main report are expected to be completed in September 1974.

17.3 Special Committees and Groups

There are two committees and a study group that perform specific functions of recording, coordinating, or exchanging data and research program information.

INTERNATIONAL GREAT LAKES LEVELS BOARD

U.S. - *Division Engineer, NCD
M. Abelson, DEPT. of INTERIOR
B. T. Jose, SLSDC
C. H. Paquette, OCE (Secretary)

CANADA - *C. K. Hurst, DPW
N. James, ENV. CANADA
R. H. Smith, MOT
N. P. Persoage, ENV. CANADA (Secretary)

WORKING COMMITTEE

U.S. - *Dr. L. H. Blakey, NCD
M. Abelson, DEPT. of INTERIOR
F. A. Blust, DEPT. of COMMERCE
J. H. Spellman, FPC
S. H. Fonda, NCD (Secretary)

CANADA - *R. H. Clark, ENV. CANADA
D. W. Quinlan, DPW
C. J. R. Lawrie, MOT
J. Bathurst, ENV. CANADA (Secretary)

SHORE PROPERTY SUBCOMMITTEE

U.S. - *D. J. Leonard, NCD
C. Kleveno, EPA
H. C. Anderson, BSF&W

CANADA - *D. W. Quinlan, DPW
J. W. Giles, PROV. of ONTARIO
C. E. Deslauriers, PROV. of QUEBEC
D. Watt, MOT
D. Brown, ENV. CANADA
Dr. J. J. Tibbles, ENV. CANADA

POWER SUBCOMMITTEE

U.S. - *J. H. Spellman, FPC
G. T. Berry, PASNY
J. Weinrub, Buffalo District
M. Abelson, DEPT. of INTERIOR

CANADA - *D. F. Witherspoon, ENV. CANADA
J. B. Bryce, HEPCO
F. Santerre, HYDRO-QUEBEC

NAVIGATION SUBCOMMITTEE

U.S. - *G. S. Lykowski, NCD
J. Aase, BUREAU of MINES
J. Officer, SLSDC
L. Ervin, DEPT. of COMMERCE

CANADA - *G. V. Sainsbury, SLSA
D. W. Quinlan, DPW
P. Klopchic, PROV. of ONTARIO

REGULATORY WORKS SUBCOMMITTEE

U.S. - *B. Malamud, Detroit District
S. H. Fonda, Jr., NCD
I. M. Korkigian, Detroit District
K. Hallock, Buffalo District

CANADA - *G. Millar, DPW
J. Bathurst, ENV. CANADA
C. J. R. Lawrie, MOT
J. Keefe, ENV. CANADA
K. A. Rowsell, DPW

REPORTS SUBCOMMITTEE

*J. Bathurst, ENV. CANADA
**D. J. Leonard, NCD
D. W. Quinlan, DPW
N. P. Persoage, ENV. CANADA
C. Larsen, NCD
B. G. DeCooke, Detroit District
I. M. Korkigian

REGULATION SUBCOMMITTEE

U.S. - *B. G. DeCooke, Detroit District
J. Miller, NWS-NOAA

CANADA - *D. F. Witherspoon, ENV. CANADA
T. L. Richards, MOT

*Chairman
**Vice Chairman

FIGURE 11–71 International Great Lakes Levels Board, Working Committee and Subcommittees

	AMERICAN FALLS INTERNATIONAL BOARD
U.S. -	*Division Engineer, NCD G. Eckbo, UNIV. of CALIFORNIA S. H. Fonda, NCD (Secretary)
CANADA -	*J. D. McLeod, ENV. CANADA H. S. M. Carver, CENT. MORTGAGE & HOUSING CORP. (Retired) N. P. Persoage, ENV. CANADA (Secretary)

	WORKING COMMITTEE
U.S. -	*District Engineer, Buffalo K. Hopkins, NFSPC S. Bartolone, NFSPC D. Carruth, KC&O-ARC.
CANADA -	*B. E. Russell, ENV. CANADA K. A. Rowsell, DPW D. R. Wilson, NPC J. E. Secords, SALTER, FLEMING & SECORD - ARC

	INTERNATIONAL NIAGARA COMMITTEE
U.S. -	Division Engineer, NCD S. H. Fonda, Jr. (Secretary)
CANADA -	R. H. Clark, ENV. CANADA N. P. Persoage, ENV. CANADA (Secretary)

FIGURE 11–72 International Technical Board and Committee

	COORDINATING COMMITTEE ON GREAT LAKES BASIC HYDRAULIC & HYDROLOGIC DATA
U.S. -	*D. J. Leonard, NCD B. G. DeCooke, Detroit District F. A. Blust, LSC, NOAA
CANADA -	*Dr. A. T. Prince, ENV. CANADA R. Smith, MOT

	INTERNATIONAL GREAT LAKES STUDY GROUP
	CO-CHAIRMEN
U.S. -	L. T. Crook, GLBC
CANADA -	Dr. A. D. Misener, UNIV. of TORONTO

	STEERING COMMITTEE
U.S. -	S. H. Fonda, NCD J. Raoul, (ALT), NCD Dr. A. P. Pinzak, NOAA Dr. D. C. Chandler, UNIV. of MICHIGAN UNIVERSITY REPRESENTATIVE
CANADA -	T. L. Richards, ENV. CANADA J. P. Bruce, CCIW Dr. A. M. McCombie, ODLF F. A. Voege, ENV. ONTARIO Dr. K. Rodgers, UNIV. of TORONTO

*Chairman

FIGURE 11–73 International Group and Committee

WINTER NAVIGATION BOARD
*Division Engineer, NCD **Rear Admiral A. Heckman, U.S. COAST GUARD G. E. Wilson, SLSDC B. Kyle, MARAD C. Pemberton, EPA L. B. Young, FPC M. Abelson, DEPT. of INTERIOR F. O. Rouse, GLBC R. W. Warren, GLC & ATTY. GEN. of WISCONSIN Rear Admiral Harley D. Nygren, NOAA

ADVISORY GROUP	
INDUSTRY	CONSUMERS
LABOR	CONCERNED CITIZENS

*Chairman
**Vice Chairman

FIGURE 11–74 Winter Navigation Board

17.3.1 International Niagara Committee

This two-man Committee (Figure 11–72), appointed by the United States and Canadian governments, is responsible for determining and recording the amounts of water exceeding the minimum flow required to maintain the Niagara Falls scenic spectacle.

Committee representatives periodically inspect all power plants in service to obtain independent power-output readings and check water-level gages to compute flows and assure compliance with all provisions of the Treaty. They investigate any discrepancies in recorded levels data between official gages and entities gages or operations and report to the two governments. The activities of the Committee are usually conducted through correspondence.

17.3.2 Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data

Recognizing that continuing independent development of the basic data would be illogical, and that early agreement upon hydraulic and hydrologic factors was mandatory, the Corps of Engineers and its Canadian counterparts formed the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data in 1953. It has advised the U.S. and Canadian agencies responsible for compiling Great Lakes hydraulic and hydrologic data.

Present membership of the Committee is shown in Figure 11-73. Three subcommittees, the River Flow Subcommittee, Vertical Control-Water Levels Subcommittee, and Physical Data Subcommittee, assist the Coordinating Committee.

17.3.3 International Great Lakes Study Group

The Great Lakes Study Group is an informal organization of Federal, State, and university personnel with ongoing research programs in the Great Lakes area. The Group provides a useful forum to assist in coordinating programs and members' activities to eliminate duplication. Leonard T. Crook, Executive Director, Great Lakes Basin Commission, is current chairman of the U.S. Section of the Study Group.

The Study Group is the only organization able to bring together for close discussion representatives (Figure 11-73) from both sides of the international boundary, with authority within their own organization to implement some coordination of the various research activities. It meets twice a year, once in each country.

There has been consideration of formalizing the International Great Lakes Study Group as a body to act with some authority for directing all areas of research efforts on the Great Lakes. Should such a proposal materialize, it would probably help the research needs related to Great Lakes hydraulics and hydrology.

17.4 Improved Regulation

The International Joint Commission study of further regulation of the levels of the Great Lakes is nearing completion. The Lake Levels Board's main report was presented to the Commission on December 7, 1973. Regulation plans have been developed and are being tested. Investigations of cost and design of regulatory works, which required intensive field exploratory phases for choosing suitable sites, design criteria, and cost estimates, are essentially completed. The unilateral study by the Corps of Engineers, dated December 1965,[42] has the only results available now. The Levels Board's findings and recommendation will consider the following:

(1) improved regulation plans utilizing existing works facilities for Lakes Superior and Ontario with no great costs involved

(2) regulation of Lakes Michigan-Huron

(3) regulation of Lake Erie

(4) further regulation of Lake Ontario, taking into account the full range of levels and flows

The requirement for the management of the Great Lakes as a system will be a definite consideration. The presently approved regulation plan for Lake Superior does not specifically consider the situation on the lower Lakes in determining the Lake Superior outflow. In the past the Board, under its discretionary authority, provided additional outflows to benefit interests on the lower Lakes. The 1964 low water-level situation was described in an earlier section. In the future the Board may consider adjustments to decrease flows to benefit interests on the lower Lakes suffering from high lake levels.

There is concern that consumptive water losses may seriously affect the levels of the Great Lakes. An assessment of future estimates of consumptive losses is provided in Section 10. Management may demand that an appointed authority, such as the International Great Lakes Levels Board, should investigate and assess all future facilities contemplating significant withdrawals or consumptive use of Great Lakes waters by means of a permit procedure.

There have been preliminary discussions indicating a continuing effort to update and keep current shore property damage assessments by responsible agencies in the U.S. and in Canada. No specific recommendation has been formulated yet. Such a continuing effort to update stage-damage relationships for shoreline reaches will be a valuable management tool in planning shoreline developments.

17.5 Extension of Great Lakes Navigation Season

Congress authorized a $6.5 million program to demonstrate the practicability of extending the navigation season on the Great Lakes and St. Lawrence Seaway in the Rivers and Harbors Act of 1970. The Act directed the Secretary of the Army, acting through the Chief of Engineers, to carry out the program in cooperation with the Departments of Transportation, Interior, and Commerce, and the Environmental Protection Agency. A Winter Navigation Board consisting of representatives of participating agencies has been established to direct the program.

The program concept consists of seven elements, each to be carried out by a lead Federal agency. The elements and lead agency designations are: Ice Information, National Weather Service; Ice Navigation, U.S. Coast Guard; Ice Engineering, U.S. Army Corps of Engineers; Ice Control, St. Lawrence Seaway Development Corporation; Ice Management in Channels, Locks, and Harbors, Corps of Engineers; Economic Evaluation, Corps of Engineers; and Environmental Evaluation, Environmental Protection Agency. A three-year program was initiated during the winter of 1971–1972. The Winter Navigation Board membership is shown in Figure 11–74.

Future demands resulting from the extension of the Great Lakes navigation season include establishment of surveillance programs on the Great Lakes' connecting channels. Surveillance programs are essential to protect shore property interests along the connecting channels. For example, because of the extensive build-up of the St. Clair-Detroit River shoreline, its susceptibility to damage, and the shoreline's general low relief, there is concern for shore property with any navigation season extension. There is serious risk of problems from ice formed on Lake Huron discharging into the St. Clair River. No facility is available to reduce the flow of lake ice into the river. The passage of vessels through the St. Clair-Detroit system may materially affect ice damaging conditions. Consequences of such action are uncertain at this time. Extensive hydraulic and related investigations will be essential to extend the navigation season on the Great Lakes successfully.

The establishment of an Ice Management Program in the Great Lakes requires efforts in specific areas:

(1) ice surveillance. Ice damage to shore structures, ice jamming, access problems, erosion, and recreational, environmental, and ecological aspects would be considered here. Prior to extensive vessel transits, surveillance of a channel under various winter ice conditions would establish base-of-comparison conditions.

(2) ice information. A central ice-reporting, forecasting, and information center is essential to winter navigation on the Great Lakes.

(3) ice forces. Solution of ice navigation problems requires basic data and full understanding of ice forces in the Great Lakes.

(4) ice control. Retaining and diversion structures in connecting channels may be required.

(5) ice supression. A number of possible methods have been utilized to suppress ice formation. However, further evaluations are necessary to determine practicability in the Great Lakes-St. Lawrence Seaway.

(6) ice effects on ships. Design for reinforcement requirements for vessels to operate in ice field are needed. Navigation interests must satisfy themselves on practicability and economic feasibility.

(7) navigational aids (for ship control). An electronic navigation positioning system is needed for ship control in restricted areas.

(8) ice management in harbors and locks. For harbors, ice management would include ice regime, entrance problems, berthing problems, loading and unloading aspects, and general ice difficulties. Ice problems at navigation locks are related to lock operation difficulties and ice management difficulties. Both areas are of continuing concern and will require accelerated programs.

(9) economic studies. Economic studies and evaluations are necessary along with investigations of the practicability of winter navigation before a decision can be reached on an extended or year-round Great Lakes navigation season.

Section 18

PROJECTED NEEDS

18.1 Additional Diversions into or out of the Basin

The following discussion provides estimates of benefits, costs, or losses if a given quantity of water becomes available for diverting into the Basin from some other basin. The reverse case will also be discussed should new diversions out of the Great Lakes be authorized.

Several factors have to be identified: the amount of such a diversion, physical means of the project, other delivery costs involved, and the cost of any necessary compensating measures in Great Lakes channels to offset the change in flow conditions. In the case of additional water being diverted into the Great Lakes, during periods of high water on the Lakes, the new diversion will increase the high water conditions and result in an increase of shore damages. During low water level periods on the Lakes, such a diversion would improve lake level conditions. No one can estimate costs for the design and construction of such compensation until the diversion is fully identified.

18.2 Value of Water for Power

18.2.1 St. Marys River

The flows necessary for power-generating facilities, navigation canals, and regulating works for the St. Marys River total 60,000 cfs. When regulation plans call for lesser flows, amounts made available to the power-generating facilities are reduced. Water exceeding 60,000 cfs is discharged through the gated control works.

18.2.2 Niagara River

The value of an additional flow of 1,000 cfs depends on the amount of water already available. The more water already flowing in the Niagara River, the less value any additional water has. Under the Treaty of 1950 the first 100,000 cfs in the Niagara River must go over the Falls during tourist hours, and the first 50,000 cfs in the remaining hours.

The United States has only the high-head PASNY plant. Canada has the high-head Sir Adam Beck plants and the low-head Ontario, Canadian-Niagara, and Toronto Power plants. The high-head plants, which make proportionally more power for the same amount of water than the low-head plants, use the first water available for power diversion after the Falls flow. For this reason the additional 1,000 cfs has the most value when the flow in the river is low.

The PASNY plant has a design capacity of 85,000 cfs and has diverted up to 105,000 cfs under high flows. The Sir Adam Beck plants have a physical limitation of 66,000 cfs because of restrictions in their intake canals. This means that during the tourist hours the remaining water in the river, averaging 100,000 cfs, can be used in the high-head plants.

TABLE 11-63 Capacities of Niagara Power Plants

Plant	Approx. Capacity	KW/CFS[1]
Robert Moses	90,000	23
Sir Adam Beck	66,400	22
Ontario	6,000[2]	12.6
Toronto	9,000[2]	7.1
Canadian-Niagara	9,000[2]	7.6

[1]These are approximate values. Curves were plotted from a number of points for the two high-head plants and enery values were developed for the varying diversions

[2]Inability to get water to the intakes under conditions of low Falls flow limits actual capacities. Particularly in the Canadian-Niagara plant, it is necessary to waste considerable water in order to use the plant

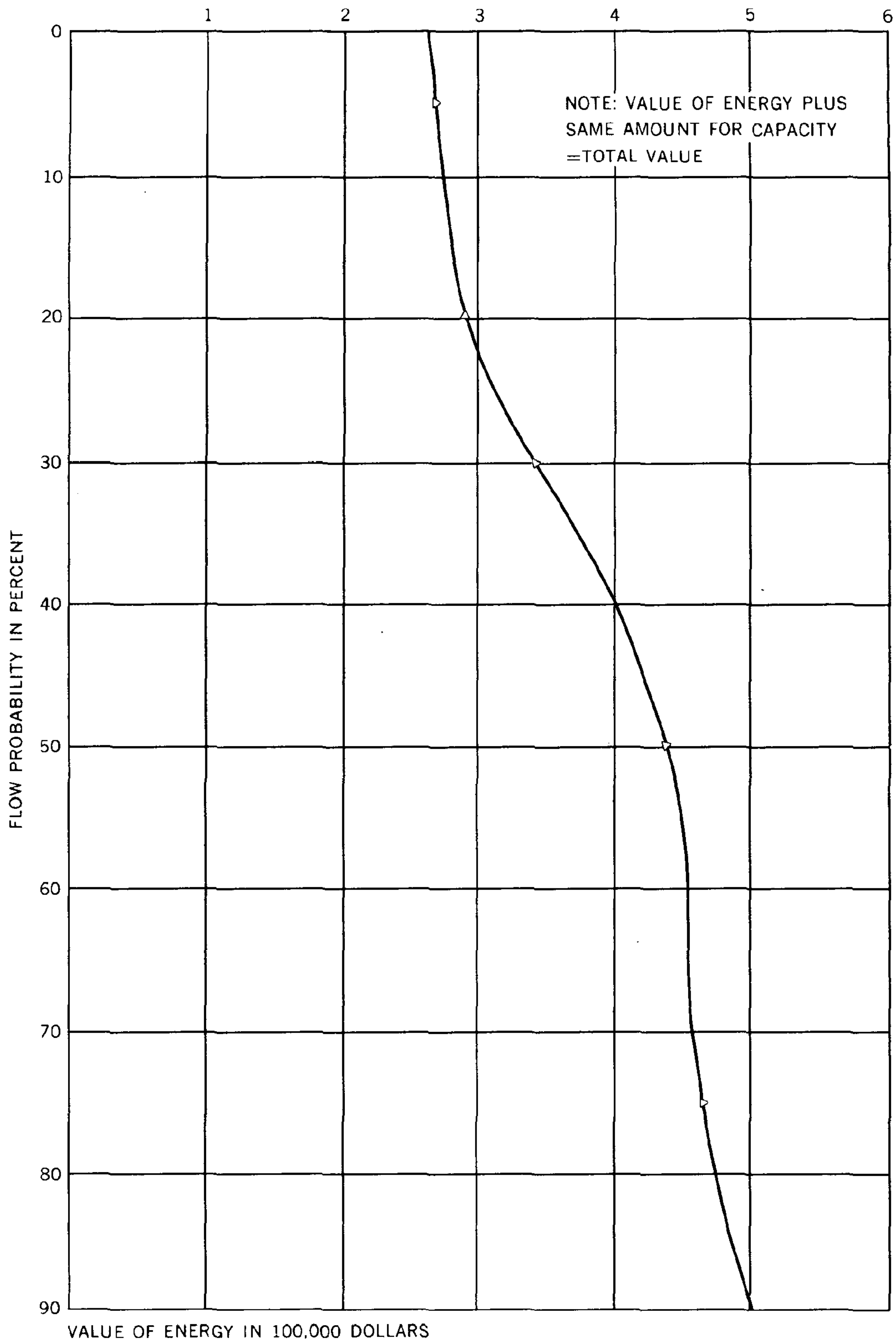


FIGURE 11-75 Value of Additional Flow for 1,000 Cubic Feet per Second Based on Entire Year—Niagara River

During non-tourist hours, when the Falls requirement is only 50,000 cfs, the high-head plant capacity of about 150,000 cfs is exceeded by the time river flow reaches average. As river flows increase above average, all additional water must be used in the low-head plants (except for use by PASNY). Additional water then has a much lower value for power production.

The control structure is used to hold proper levels in the upper Niagara River. Power diversions would otherwise reduce levels of flows. The control structure can maintain 50,000 cfs over the Falls while maintaining proper levels up to river flows of 206,000 cfs, which occurs approximately 50 percent of the time. Above that discharge amount the structure can no longer control the required flow over the Falls and the excess water flows around the structure. The Canadian low-head plants, at a discharge of 225,000 cfs, catch and use this extra flow. Above this discharge most of the additional water goes over the Falls. Because flow frequencies vary depending on the month, the value of water varies with the month of the year used to determine the value.

All of these factors have been worked into Figure 11–75 (power value curve). The curve value is based on the value of energy developed, plus an equal value for additional plant capacity for 1969 conditions. The capacity value assumes that additional water would be made available over an extended period. A short-term diversion would have only half the dollar worth. The dollar values are based on an energy value of 2.67 miles per kilowatt. Energy produced was measured by manufacturers' ratings and Gibson test ratings for the various plants for approximate heads.

If Treaty flow requirements over the Falls were ever changed, an alternative suggested in Subsection 18.4.2, the assumptions used to derive the value of water for power at Niagara would change and hence the value of power would change.

18.2.3 St. Lawrence River

A flow of 1,000 cfs can mean the annual production or loss of $140,000 of power energy besides the value of peak capacity and the industrial production involved.

18.3 Value of Water for Navigation

The value of water for commercial navigation on the Great Lakes is presented in Appendix C9, *Commercial Navigation*. The effects on navigation of a change in lake levels depend on the type of shipping evaluated, i.e. intralake or interlake traffic. Also, the dollar value of the additional shipping depth available varies from month to month during the April-to-November navigation season. A change in depth of .1 foot during the navigation season on Lakes Superior, Michigan-Huron, Erie, and Ontario at low water datum elevation on each Lake for all traffic provides $800,000 benefit or loss to shipping (both U.S. and Canadian interests). This value is representative only when the Lakes are at or near low water datum elevations.

18.4 Alternatives for Regulation of Great Lakes Levels and Flows

The Great Lakes are a challenge to those concerned with developing and managing their water resources. There are both international implications and a diversity of interests concerned with the levels and outflows of the Lakes, including hydroelectric power, navigation, water supply, and recreation.

The IJC study, *Regulation of Great Lakes Water Levels*, investigated alternative regulation schemes utilizing all of the Lakes as a system and assessing the economic effect on the diverse interests. The final report considers structural alternatives for further regulation of Great Lakes levels and flows. The study also investigates nonstructural alternatives in the form of improved ways of regulating Lakes Superior and Ontario at minimal cost.

18.4.1 Other Structural Alternatives Relating to Levels and Flows

In the event that the regulation of Lakes Michigan-Huron is not feasible, the U.S. government is committed to restoring the levels of these Lakes to 1933 conditions. A recommended means for restoring these levels was discussed in other subsections. Structural means may be necessary to compensate for effects of river development and landfills along the connecting channels.

Studies expected to be undertaken for extension of the navigation season may require structural means to stabilize flow conditions in the connecting channels. It would appear that some type of temporary or permanent structure, or a combination of both, would be required to control the ice floes passing through such critical navigation areas as the outlet of Lake Huron. A temporary structure could be a winter-installed, modified version of the type of floating boom utilized in the Lake Erie-Niagara River outlet location.

A possible permanent, less expensive structure might be a system of rockfill spur dikes along the St. Clair River to reduce or prevent large ice-runs out of the Lake. One might design many other types of structures to prevent ice-runs out of Lake Huron, but all would be very costly and probably objectionable to many people, including recreationists and riparian owners. A possible solution is artificially strengthening the ice arch which normally forms in the funnel-shaped Lake Huron outlet. Large mesh nylon nets frozen into the ice-covered arch would help prevent the intermittent break-up of the arch under wave action and premature warming periods that may occur in the winter. A fixed structure could be installed to maintain a fixed navigation channel opening.

Additional structural alternatives may be possible for improved control of ice on connecting rivers with hydroelectric power developments subject to low winter temperatures such as the Niagara and St. Lawrence Rivers. This often presents many varied and difficult problems. The Power Authority of the State of New York and the Hydro Electric Power Commission of Ontario have taken significant measures to achieve control of these rivers in the winter. Ice booms have proved to be of great value on the Niagara and St. Lawrence Rivers in forming and retaining ice covers where natural ice covers are uncertain or unstable. In the case of the St. Lawrence River, extension of navigation will necessitate modifying regulation of the ice boom systems presently utilized for stabilization of the ice cover. The practicality of winter navigation on the St. Lawrence River without causing damage to power generation and shore property interests has not been demonstrated.

Structural alternatives for the preservation and protection of Great Lakes shoreline properties are discussed in detail in Appendix 12, *Shore Use and Erosion.*

The American Falls International Board is investigating the feasibility of constructing a control structure in the lower Niagara River to raise the level of the Maid-of-the-Mist Pool to approximate what existed before diversion of water for hydroelectric power generation. Increased water in the Pool would improve appearances in the vicinity of the Falls by covering the lower levels of the talus accumulation at the base of the American Falls, by covering the rock ledges on the Canadian shore, and by covering other exposed debris at several shore locations. Construction of a control structure at the head of the Whirlpool Rapids will create a water-level differential, which, in combination with the large, steady river discharges (50,000 cfs or 100,000 cfs Treaty flows), will provide a significant hydroelectric potential. Therefore, such a structural measure could provide for a multi-purpose project.

18.4.2 Nonstructural Alternatives

The existing international treaties, orders of approval by the International Joint Commission, and the supervision by its Board of Control are the principal authorities limiting use of the hydroelectric resources of the St. Lawrence and Niagara Rivers. The value of these resources depends largely upon how well the power they produce fits the demands of the areas they serve. At Niagara Falls, the flows required by the Treaty of 1950 to provide for the scenic beauty of the Falls compete with the ideal distribution of these flows for power. Pumped-storage facilities in both Canada and the United States have been provided and a river-dispatching procedure developed which permits full utilization of the flows available for power while maintaining the Falls flows specified by Treaty.[2] A change or amendment of the Treaty of 1950 on Niagara Falls flows could provide increased diversion for power purposes and is considered an alternative for furnishing additional power. However, structural measures may be necessary to provide for added compensation in order to maintain an acceptable scenic appearance of the waters flowing over Niagara Falls. As an example, if tourist-hours flow minimums would be reduced to 70,000 cfs instead of the present 100,000, it may be feasible, by a submerged weir scheme, to provide nearly the same scenic appearance of the Falls. Detailed studies would have to determine the feasibility of this alternative.

The establishment of building codes and zoning restrictions for those individuals building along the shoreline of the Great Lakes is covered in Appendix 12, *Shore Use and Erosion.*

The establishment of a permit policy for approval of large water withdrawals from the Great Lakes may be necessary to constrain consumptive water losses that may occur with future developments. The case of the City of Detroit's water supply intake facility at the lower end of Lake Huron was cited on previous pages.

Other possible nonstructural alternatives include previously mentioned control or modification of weather conditions over the Great Lakes. If techniques can be developed, these applications may modify precipitation over the Basin. Also, one might explore ways to modify the evaporation of Great Lakes water.

18.5 Lake Stage Forecasts in Great Lakes Weather Forecasts

In recent years the National Weather Service has been preparing a plan to forecast lake stages. Actual meteorological observations transmitted to a forecasting office would be needed to verify the forecasts. Accurate long-term water-level forecasting demands the determination of long-range weather forecast inputs.

Several people have worked on a lake stage forecast method for Lake Erie in recent years. While these methods yield good forecasts, they cannot be used without meteorological input, such as hourly winds at a number of shore locations around the Lake. It would be necessary to telemeter lake stages from water level gaging stations at specific locations from the Great Lakes. A forecasting scheme operating with these inputs could be very helpful in predicting major surges similar to those experienced at both the eastern and western ends of Lake Erie. No lake stage forecast procedures are operating now. An immediate need exists for the National Weather Service to initiate such services to safeguard lives and property.

18.5.1 Long-Range Weather Forecasting and Modification Techniques

In recent years technical investigations and research projects have partly succeeded in producing precipitation as well as reducing heavy snowfall over populated Great Lakes shoreline areas. The snowstorm suppression technique makes more snow fall over the Lake and less on the land or on a wide area and thus to a lesser depth. Such control may save millions of dollars annually by reducing damage, storm clean-up, and indirect losses. As the feasibility of modifying the weather over large areas of the Great Lakes advances, long-range weather forecasting should also become more reliable.

18.6 Great Lakes Hydraulic Modeling Efforts

Great Lakes hydraulic mathematical modeling combines, in a computer program, the physical hydraulic-hydrographic relationships which govern the outflow of a given Great Lakes channel. Input data describe water supply conditions to the affected Lake or Lakes that have occurred historically or have been derived by statistical methods. When such a hydraulic mathematical model has been developed and verified adequately, a great variety of problems may be solved at minimal expense.

The IJC Water Levels of the Great Lakes Study utilized mathematical simulation in computer models.[32] Mathematical models for the St. Marys, St. Clair-Detroit, and Niagara Rivers have been developed and tested. Studies using them for selecting regulatory work sites and design are under way. Replacing physical models with these mathematical simulations has not only substantially reduced actual development and operational costs, but provides greater engineering application. They also completely eliminate continuing maintenance costs of large-scale physical models.

18.6.1 Data Needs for Modeling Purposes

There is a constant need for field discharge-measurement data on the connecting rivers to verify the mathematical models. Verifications of outflows for a channel under varying conditions are essential. The Detroit District, Corps of Engineers, has to provide a continuing program of measurements of the Great Lakes connecting channels, normally carried out in a 5-year program. Given the funds, these planned periodic measurements are made as scheduled.

Updated, detailed hydrographic surveys are required of the St. Marys River and of a portion of the Detroit River from Amherstburg Channel upstream to the head of Belle Isle in order to improve the two existing mathematical models. The hydrography covering these two rivers is based on surveys completed many years ago to satifsy charting specifications, and does not provide data for complete, detailed hydraulic modeling.

18.6.2 Model Needs

Numerous hydraulic model requirements need to be filled in order to provide the detailed investigations for carrying out an extension of the navigation season on the Great Lakes or the deepening of the Great Lakes connecting channels to a 30-foot depth. Modifying an existing mathematical model might be enough.

A mathematical model of the International Rapids Section of the St. Lawrence River is needed. The approximate cost of development of such a model is $100,000. St. Lawrence Seaway Development Corporation plans to construct a physical model of the reach of the St. Lawrence River below the International Power House and Snell Navigation Lock to the International Bridge. In this reach, the divided channels of the river at times produce currents hazardous to navigation.

A physical model of the St. Marys Rapids reach of the St. Marys River, including three power and navigation canals, is also needed to investigate future replacement of structures, anticipated new navigation, lock replacements, and navigation channel improvements.

Additional deepening of Great Lakes connecting channels was authorized in 1952 and largely completed in 1962. Commensurate deepening of harbors came in the period 1959 to 1965, following studies begun in 1956. The deepening generally increased the system depth from 25 to 27 feet in the downbound channels and from 21 to 27 feet in upbound channels. Consideration should be given also to a study of the feasibility of a 30-foot or 32-foot navigation system. Appendix C9, *Commercial Navigation*, discusses the economic feasibility of deepening the Great Lakes-St. Lawrence Seaway System.

A deepening project will necessitate detailed hydraulic studies. Additionally, the elimination of a navigation lock for the St. Lawrence River at Iroquois Lock and Dam site appears feasible. Detailed hydraulic studies are necessary in order to substantiate enlargement of the navigation channel in this reach of the St. Lawrence River.

18.7 Implications of Water Quality Considerations

Water quality in the Great Lakes undergoes rather significant short-term and seasonal changes in addition to the long-term trends. Wind, waves, and currents are factors in short-term changes, while ice cover, temperature, and radiation cause seasonal variations. The long-term natural aging (eutrophication) of the Lakes is related to the cultural and industrial development of the Basin and to other factors involved in the process. Appendix 7, *Water Qualify*, and Appendix C9, *Commercial Navigation*, discusses these subjects in more detail.

The Detroit River carries large quantities of pollutants into Lake Erie from municipal and industrial developments along the river. The Niagara River discharges water of somewhat deteriorated quality into Lake Ontario. A report[20] by the International Great Lakes Pollution Board describes the water quality conditions of Lakes Erie and Ontario. Because the flows of the Detroit and Niagara Rivers constitute such a large proportion of the total water supplies to Lakes Erie and Ontario, their pollution effects on main-body waters of these Lakes are significant. Therefore, in the design and construction of regulating structures and of excavated channels in the St. Clair-Detroit and Niagara Rivers, post-project conditions must provide maintenance of profile conditions and provide for no worse than specific pre-project water quality standards.

In the ongoing IJC study, *Regulation of Great Lakes Water Levels*, the International Great Lakes Levels Board will be coordinating with the International Great Lakes Pollution Board the regulatory works requirements for all final regulation plans recommended to the International Joint Commission. Any recommended plans will fully consider all conditions and criteria cited by the Pollution Board. As part of their shore property investigations, the Levels Board is closely examining fish and wildlife habitat areas along the connecting channels so as not to harm these interests.

Special design features and site considerations may be necessary to minimize impact on the local environment, particularly during construction. In the regulatory works investigations, the cost of any necessary remedial measures during construction of any project will be charged against the total cost of the project. Special preventive measures may include cofferdam arrangements and onshore disposal of dredged materials to minimize any effects of the water quality conditions.

A preliminary evaluation of Regulation Plan 64-MH-9 by the Federal Water Quality Administration, Cleveland Program Office for Lake Erie, indicates that regulation of lake levels in itself hardly affects water quality. Under this Plan, the average level of Lake Erie would be reduced less than 0.4 foot, representing a reduction of average volume by 0.7 percent, an insignificant influence on constituent concentration. However, regulated inflows and outflows on Lake Erie and their timing are important. It was determined that this plan would lower water quality in the Detroit River and the western basin because of low flows in winter and spring.

Flushing the Lakes with low-nutrient water has been suggested as a restorative measure. Assuming no inflows to the Lakes, and keeping outflows at their respective mean values, it would take 184 years for Lake Superior and 2½ years for Lake Erie to empty. This is a hypothetical situation. In reality, there are always inflows and it is not possible to empty the Lakes completely. In view of the huge volumes of the Lakes and the very large annual amounts of their natural water supplies, logical limits to this solution would be to increase natural supplies from outside the Basin. This involves consideration of water source possibilities, the problems relating to diversion of such water into the Lakes, and, unless offsetting lake outflow facilities were added, the harm to shore property interests from increased lake levels from added supplies.

The most suitable Lake for flushing would be Lake Erie. Lake Erie's needs are greater and the flow-through time more favorable than for the other Lakes. A hypothetical example shows that increasing the Lake's average outflow rate by 20 percent would require augmenting its water supply by 40,000 cubic feet per second. For flushing Lake Erie, the additional flow obviously would be applied at the western end of the Lake. Because northern areas are the most likely out-of-the-Basin source of low-nutrient water, the flow might be introduced upstream of the St. Clair-Detroit River system and conducted via that system to become a part of the Detroit River discharge to Lake Erie. However, analysis of available data shows that further research and pilot scale testing would be required to assess the effects and practicalities of applying such a technique on Lake Erie.

The dredging of organic bottom sediments from the shallow western basin of Lake Erie has been suggested as a restorative measure. The organic dredgings would be placed in diked enclosures to form islands in the Lake. Associated with the suggestion is an idea that improvement of water quality in certain areas might be obtained by placing and shaping the islands so as to redirect currents through the western basin. The installation of training dikes to control the direction of Detroit River flows entering the Lake would be considered also. Any adverse effects would have to be evaluated. In order to improve prediction of the effects of the islands and dikes on current direction, a hydraulic model of the western end of the Lake would be used, so that various island and dike arrangements could be tested before designing the prototype. It may be that improvements of the situation would be largely due to the removal of organic bottom sediments, and that current redirection could effect benefits to certain inshore areas with somewhat less desirable results in other areas. Appendix 4, *Limnology of Lakes and Embayments*, discusses these problems in detail.

A benefit of regulation might be improved water quality in some of the Lakes, particularly in Lake Erie. However, to define the benefit to be obtained may be difficult to demonstrate. Water inflow to a Lake may possibly be scheduled when the quality in the upstream Lake is higher than that in the lower Lake. Permanent water quality monitoring stations should be established in the Lakes to record water characteristics and associated data. These stations, properly calibrated with the Lake proper, would indicate the long-term changes in water characteristics and also provide information to assist possible scheduling of water releases from each regulation Lake. Research should establish the optimum environmental conditions for the Great Lakes waters and all lake regulation plans should be modified to achieve them.

18.8 Wastewater Management Programs

Authorization has been given to study the feasibility of wastewater management programs in the Great Lakes Basin. Initially, studies are being made for the Detroit, Cleveland-Akron, and Chicago metropolitan areas as part of the Great Lakes rehabilitation program. These locations were chosen because of their critical natures as sources of pollutants. The studies are a joint effort by the Environmental Protection Agency and the Corps of Engineers to solve regional pollution problems by eliminating the disposal of inadequately treated wastes into our inland waters and by evaluating the reuse of adequately treated wastewater.

18.8.1 International Great Lakes Waste Water Quality Agreement

The Treaty of 1909 between the United States and Canada provides that no action may be taken that affects the level of flow of their boundary waters, except under prescribed procedures for coordination and agreement between the two nations. The procedures normally involve a reference by one or both governments to the IJC, which then conducts appropriate investigation and reports back to the two governments. The Treaty provides further that the waters are not to be polluted on either side of the international boundary to the injury or health of property on the other side of the boundary. Unilateral implementation of preventive measures such as pollution abatement obviously would be in accord with the Treaty, but any restorative measures having trans-boundary effects on levels or flows of the Lakes would require Commission approval prior to implementation. With respect to questions of pollution of the Lakes, the Commission may be asked, among other things, for recommendations regarding remedial measures.

A United States-Canadian agreement on Great Lakes water quality matters was signed by U.S. and Canadian leaders in Ottawa, Ontario, on April 15, 1972. At that time, the two countries adopted as their joint objective the elimination of water pollution in the Great Lakes. It is anticipated that the International Joint Commission will be responsible for overseeing the agreement.

18.9 Great Lakes Connecting Channels and Harbors Study

The Corps of Engineers has been directed by the U.S. Congress to review the report of the Chief of Engineers on the Great Lakes connecting Channels, with a view to determining the advisability of further improvements to the Great Lakes navigation system in the interest of present and prospective deep-draft commerce, with particular consideration to improvements for the safe operation of vessels up to the maximum size permitted by the Poe Lock in the St. Marys Falls Canal. A survey study was initiated in 1971 to investigate possible improvement of the Great Lakes navigation system, which includes Lakes Superior, Huron, Michigan, and Erie, together with their connecting channels and harbors. The system is linked to overseas trade by the Welland Canal, Lake Ontario, and the St. Lawrence Seaway.

The existing navigation project for the Great Lakes connecting channels was authorized on March 21, 1956. The improvement provided for increasing controlling depth from 24.8 feet and 21 feet below low water datum in downbound and upbound channels, respectively, to a controlling depth of 27 feet below low water datum in both channels. Therefore, a safe draft of 25.5 feet for Great Lakes freighters is provided, with allowances for squat of vessel underway, wave action, and bottom conditions. These project depths have been available since June 1962. Subsequent authorizations related to harbor improvements have provided similar and commensurate project depths at principal harbors on the Great Lakes.

The new Poe Lock, placed in operation in 1969 at Sault Ste. Marie, is 1,200 feet long, 110 feet wide, and 32 feet deep over the sills. It has led to construction of two new self-unloading supercarriers, both of 105-foot beam, one 1,000 feet long, and one 858 feet long, and both designed for a draft capability of 32 feet of water. The economy to be realized by larger craft points to construction of more of these large vessels, which will not be able to operate at full draft and optimum safety in the existing channels, harbors, and facilities. These constructions, with the exception of the new Poe Lock, were designed for maximum vessel dimensions of 730 feet long, 75-foot beam, and 25.5 feet of draft at low water datum.

To provide for ease of navigation and the safe passage of the larger vessels, it has been recommended that various bends and reaches of the St. Marys, St. Clair, and Detroit Rivers be widened and deepened. The investigation will determine to what extent, if any, the connecting channels should be improved with corresponding determinations of improvements at Great Lakes harbors. Solutions must consider not only commercial benefits but also effects of any modifications on the environment to include those navigation-related problems pertaining to shore property. The analysis of the system will also take into consideration the effect of an extended navigation season, the need for additional lock capacity or lock modification at Sault Ste. Marie, and other changes that may affect the Great Lakes-St. Lawrence Seaway System.

It is planned that interim reports on individual harbors and specific sections within the Great Lakes navigation system be prepared as soon as practical where economic and environmental justification can be established because of deep-draft bulk cargo traffic.

There are several ongoing studies by the Corps of Engineers that have some relation to the Great Lakes Connecting Channels and Harbors study:

(1) International Joint Commission *Regulation of Great Lakes Water Levels* was previously discussed in detail in this appendix.

(2) Lake Erie-Lake Ontario Waterway study considers the need for an additional deep-draft waterway between Lake Erie and Lake Ontario, with possible canal located in the United States. The existing waterway is the Welland Canal in Canada.

(3) St. Lawrence Seaway Additional Lock study is considering additional locks in the United States section of the Seaway on the St. Lawrence River. Investigations in this study will determine:

(a) nature of improvements desired. This would include depths and widenings desired and the areas involved.

(b) developments which now are under consideration or which local interests propose to be undertaken in connection with the desired improvements

(c) expected benefits from the desired improvements such as accommodation of larger vessels, ease of maneuvering, safety of navigation, anticipated potential commerce by commodities. The desired information should particularly pertain to the prospective commerce anticipated to use the Great Lakes navigation system.

(d) statements as to existing environmental conditions and planned future programs which will affect the environmental setting of the connecting channels and harbors

Final design of any connecting channel modification or improvement projects must determine the effects of such channel improvements upon the water levels, velocities, flow distributions, and the required compensation works to offset the channel enlargements.

18.10 Design Wave Heights—Statistical Information

Accurate wave-height measurements have been recorded only in recent years at a few selected locations throughout the Great Lakes. Most of these locations have recorded waves for only relatively short periods. To develop design wave-height statistics for construction of shoreline developments, theoretical wave heights are calculated. Detailed design wave-height data have been determined only for the immediate areas of the various Federal harbor and protective structures projects on the Great Lakes. The development of ultimate water level data is described in Section 8 with tabulation of such values available from U.S. Army Corps of Engineers, North Central Division.

In order to provide specific design wave-height and nearshore current data for shoreline construction purposes, more precise determinations of such detailed information are needed for relatively short segments of shoreline.

GLOSSARY

basis-of-comparison data—these recorded lake levels and outflows adjusted to fixed diversion and lake outlet conditions are used as a base in testing regulation plans.

compensating works—hydraulic structures (channel improvements, locks of dams) built to control the outflows and levels of a lake or a lake system.

connecting channels—the Detroit River, Lake St. Clair, and St. Clair River comprise the connecting channel between Lake Erie and Lake Huron. This connecting channel has been deepened to provide a controlling project depth of 27 feet. Between Lake Huron and Lake Superior, the connecting channel is the St. Marys River.

consumptive use—quantity of water withdrawn or withheld from lakes or consumed in various processes and not returned.

criteria for regulation—the standards, or governing conditions, used in designing a regulation plan.

crustal movement—the change in level of the earth's surface at a location with respect to another location. Crustal movement is expressed as a differential rate of level over time. This process is still continuing and affects differences in elevations.

cubic feet per second month (cfs-month)—unit of supply used in testing regulation plans. It is equivalent to the volume of water represented by a flow of one cubic foot per second for an average month of $^{365}/_{12}$ days.

diversion—man's changing the natural course of water as it drains toward the sea from one drainage basin to another.

divide—the line of separation between drainage systems.

embayment—an indentation in the shoreline forming a bay.

escarpment—a topographic landform developed as a more or less continuous line of steep slopes facing in one general direction which are caused by erosion or by faulting.

fetch—the unobstructed course (path) of wind blowing across a lake.

frequency of occurrence—number of times an event of a certain magnitude occurs or has been exceeded, normally expressed as events per hundred years or as the percent change of occurrence in any year.

hydraulic capacity—the maximum amount of water a channel is physically able to carry under given stage conditions.

ice retardation—the difference between the amount of water discharged at given lake and river stages under open water conditions and under ice conditions.

lake diversions—diversions of water into or out of a lake basin. Diversions into a lake have the effect of raising the water levels of the lake into which the diverted water is charged and of raising the levels of the lakes downstream through which the diverted water must pass on its way to the sea. Diversions of water out of a lake basin have the converse effect on the levels of the lakes downstream from the point of diversion.

lake drainage area—the drainage area of a lake measured in a horizontal plane enclosed by a drainage divide.

lake drainage basin—that part of the surface of the earth that is occupied by a drainage system of rivers and lakes.

lake inflow—contribution to a given lake. In the Great Lakes, by the outflow from the lake immediately upstream through the river connecting the lakes.

lake level forecasting—the prediction of future lake levels. The Lake Survey Center, NOAA, Department of Commerce, the Federal agency in the United States that is responsible for collection and dissemination of Great Lakes water level data, has for a number of years published a monthly bulletin of lake levels for the previous year and the current year to the date of the bulletin, compared with long-term averages and extremes of levels that have been experienced. The Detroit District, Corps of Engineers, forecasts the probable levels for six months in advance for use on the bulletin, which is widely distributed around the Great Lakes.

lake outflow—the amount of water flowing out of each of the Great Lakes through its natural outlet channel.

lake regulation—control of lake levels by controlling the amount of water flowing out of the lake in accordance with a rule designed to accomplish certain goals.

lake storage—the volume of water storage areas of the Great Lakes constitute a characteristic feature since relatively small changes in the levels of the lakes involve enormous quantities of water.

moraine—an accumulation of glacial drift having initial constructional topography, built by the direct action of glacier ice.

net basin supply—represents the supply of water a lake receives from its own basin less the losses by evaporation from the lake surface and leakage through the bottom.

net total supply—represents the total supply of water to a lake from all sources less the losses from the lake surface and bottom. The net total supply is the net basin supply plus outflow from lake upstream and diversion into the lake.

physiography—a descriptive study of the earth and its natural phenomena, such as climate, surface, etc.

regulation plan—a method of determining at the beginning of a period the amount of water to be released from a lake(s) in order to control lake levels and outflows to accomplish certain aims.

rule curve—a set of agreed upon conditions, summarized in a graph or a table for the purpose of lake regulation.

seiche—an oscillation of the water surface of a lake following a water level disturbance. In the Great Lakes area, any sudden rise in the water level in a harbor or along the shore of a lake.

stage—water surface expressed in feet above or below a plane of reference.

surge—a water level disturbance resembling a large wave or a great roll of water crossing a lake or harbor.

till—nonsorted, nonstratified sediment carried or deposited by a glacier.

ultimate water level—level obtained from superimposing on the still water level, the temporary storm rise and the wave run-up. The run-up is the maximum level reached after a wave has broken.

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ADDENDUM

The Addendum contains data pertinent to the information requirements of other Great Lakes Basin Framework Study work groups and individuals seeking additional specific data or sources. Historical data furnished here are the outflows from the St. Clair and Detroit Rivers and several diversions into or out of the system. Other data, i.e., derived data, such as ultimate water levels developed for generalized reaches of Great Lakes shoreline, are available at the North Central Division, Corps of Engineers Office, 536 S. Clark Street, Chicago, Illinois 60625.

The data are listed in the following sequence:

Outflows

St. Clair River (1957–1971)
Detroit River (1936–1971)
St. Clair and Detroit Rivers (1860–1956)

Diversions

Ogoki-Long Lake Projects (1939–1970)
Chicago Diversion (1900–1970)
Illinois and Michigan Canal (1860–1910)

TABLE 11-64 Mean Monthly Discharge of St. Clair River at Port Huron, Michigan in Thousands of Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1957	136	150	170	171	176	179	184	185	180	178	173	171	171
1958	135	126	166	168	174	174	172	171	167	165	159	143	160
1959	105	111	150	158	163	170	170	170	171	170	172	170	157
1960	172	141	160	174	187	195	201	203	202	200	191	193	185
1961	171	180	181	181	182	184	185	186	185	184	181	178	182
1962	143	143	178	186	189	193	192	189	187	181	175	171	177
1963	141	140	160	168	171	173	174	174	171	168	163	156	163
1964	128	135	148	147	157	157	159	159	159	157	154	152	151
1965	139	134	149	157	166	174	177	174	179	184	184	184	167
1966	181	169	182	184	187	187	189	187	182	179	176	175	182
1967	175	172	172	180	185	191	195	195	194	188	193	185	185
1968	170	185	184	182	186	190	197	200	201	203	202	200	192
1969	187	194	193	192	200	206	212	216	214	212	209	208	204
1970	163	175	201	196	203	208	211	213	212	209	208	210	201
1971	207	202	205	209	216	218	224	224	224	219	217	213	215

TABLE 11–65 Monthly and Annual Flow of the Detroit River at Detroit, Michigan in Thousands of Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1936	112	143	152	157	158	162	160	157	159	160	154	153	152
1937	150	128	147	153	162	161	162	161	159	155	155	151	154
1938	122	155	144	163	167	174	178	179	178	177	172	170	165
1939	162	100	131	175	176	181	185	183	184	180	176	171	167
1940	136	125	142	173	167	173	176	174	177	176	172	173	164
1941	156	127	150	166	172	173	172	169	166	171	171	171	164
1942	155	116	155	182	183	193	193	190	189	185	184	186	176
1943	155	148	180	190	201	202	209	211	210	206	203	204	193
1944	142	168	171	196	196	200	202	198	197	198	193	194	188
1945	157	157	180	190	197	201	206	202	200	205	195	195	190
1946	180	142	193	200	198	208	205	201	196	191	186	184	190
1947	159	157	183	200	196	198	204	207	207	204	200	196	193
1948	185	176	194	195	202	199	201	200	194	185	178	181	191
1949	187	181	155	182	179	179	183	182	176	173	167	167	176
1950	163	154	152	180	173	176	185	186	188	188	186	189	177
1951	173	175	190	196	201	207	214	216	215	217	219	202	202
1952	204	209	216	224	223	228	234	236	234	226	215	215	222
1953	212	206	209	213	216	220	225	225	222	216	207	204	215
1954	173	160	208	208	210	213	220	218	216	225	218	215	207
1955	212	193	208	206	208	215	213	211	202	195	190	188	203
1956	122	118	171	188	204	195	198	200	197	190	185	182	179
1957	148	152	181	180	182	184	192	186	188	182	176	186	178
1958	146	140	175	164	180	176	176	176	174	172	167	145	166
1959	110	124	159	169	168	173	172	173	174	174	177	178	163
1960	183	150	167	186	190	200	202	204	204	201	195	200	190
1961	175	181	187	188	188	187	189	190	187	187	185	183	186
1962	156	143	182	190	190	194	192	190	189	184	179	173	180
1963	148	140	169	175	176	176	176	177	175	170	168	160	168
1964	134	137	152	155	164	161	162	163	163	160	157	156	155
1965	142	142	158	168	172	176	178	179	180	185	185	188	171
1966	185	176	186	187	188	188	188	189	186	182	180	187	185
1967	186	171	182	187	191	194	200	196	196	194	200	193	190
1968	177	197	190	191	193	200	204	206	205	206	205	200	198
1969	184	198	202	207	212	213	220	222	219	215	215	209	210
1970	160	176	205	206	208	214	217	217	216	214	214	215	205
1971	212	198	217	218	219	223	225	228	226	221	219	218	219

TABLE 11–66 Monthly and Annual Flow of the St. Clair and Detroit Rivers in Thousands of Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1860	225	202	219	220	228	233	232	234	232	228	222	210	224
1861	208	198	222	214	220	230	235	240	235	234	230	228	224
1862	207	200	210	224	227	230	228	231	232	233	227	224	223
1863	211	200	203	209	196	223	223	221	220	222	221	210	213
1864	196	205	194	211	215	215	215	214	210	210	203	204	208
1865	178	155	197	196	206	210	218	220	218	215	208	200	202
1866	194	190	180	197	198	203	207	210	208	206	206	195	200
1867	189	199	172	207	205	213	218	220	217	213	208	199	205
1868	195	175	209	204	205	206	207	205	202	201	201	198	201
1869	180	167	162	192	195	198	207	214	214	210	212	204	196
1870	187	167	174	199	209	222	224	222	227	222	216	209	206
1871	187	166	218	224	230	230	231	228	216	208	208	188	211
1872	196	194	186	193	200	205	206	206	206	204	206	189	199
1873	188	185	189	189	203	216	215	218	217	218	216	210	205
1874	185	166	206	209	211	218	217	218	219	217	210	210	207
1875	206	206	203	211	213	216	219	219	221	221	220	207	214
1876	215	207	207	205	218	227	238	239	238	234	231	229	224
1877	210	208	156	192	194	226	228	227	222	223	222	216	210
1878	217	156	185	209	212	215	221	221	216	219	217	208	208
1879	209	165	197	202	204	206	206	206	207	204	206	203	201
1880	197	188	194	192	202	211	216	216	216	212	210	194	204
1881	192	207	202	203	206	213	217	216	216	222	225	218	212
1882	208	202	201	208	211	215	219	221	222	220	218	203	212
1883	204	210	198	209	219	222	230	235	231	227	232	230	220
1884	216	178	210	222	226	227	231	230	226	232	229	220	221
1885	216	226	213	219	230	232	233	236	235	231	228	222	227
1886	186	169	208	236	241	242	239	237	236	235	232	220	223
1887	216	221	207	210	222	224	228	226	220	222	215	209	218
1888	203	204	211	208	215	220	220	222	219	216	212	209	213
1889	198	188	194	188	198	206	210	211	211	208	202	197	201
1890	194	189	187	188	192	197	204	208	204	203	198	194	196
1891	184	187	169	184	199	197	198	198	196	192	189	186	190
1892	181	150	162	181	182	187	191	196	195	196	191	184	183
1893	159	184	182	186	192	198	202	203	199	199	197	189	191
1894	188	181	191	188	194	203	207	205	202	200	198	192	196
1895	188	187	182	175	182	191	191	190	188	186	178	170	184
1896	171	110	129	171	173	182	184	184	183	181	181	179	169
1897	174	166	169	177	184	190	194	196	193	191	188	182	184
1898	178	161	182	187	188	191	195	194	194	189	188	182	186
1899	174	173	114	167	179	194	201	201	200	194	191	184	181
1900	150	178	178	177	176	185	192	193	197	198	200	192	185
1901	162	105	137	126	202	201	203	205	201	199	196	165	175
1902	126	134	181	182	186	190	190	192	188	184	185	176	176
1903	136	125	167	178	180	184	188	190	192	196	191	160	174
1904	155	143	141	181	189	197	200	203	202	202	199	179	183
1905	112	118	153	196	196	202	204	205	205	203	200	177	181
1906	170	148	142	157	202	203	205	204	201	197	193	182	184
1907	146	158	179	189	195	199	204	203	203	199	194	190	188
1908	175	151	163	187	194	200	205	202	198	190	190	187	187
1909	168	118	148	181	184	190	191	191	190	188	183	171	175

TABLE 11-66 (continued) Monthly and Annual Flow of the St. Clair and Detroit Rivers in Thousands of Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1910	133	144	160	183	184	190	192	186	187	184	187	167	175
1911	134	142	170	181	183	191	191	185	172	183	194	186	176
1912	133	137	149	168	180	181	190	187	191	191	191	190	174
1913	178	142	165	183	182	185	198	197	192	192	191	185	182
1914	155	148	155	175	178	183	193	190	190	184	180	169	173
1915	149	159	160	173	176	179	183	185	182	178	175	175	173
1916	184	157	129	153	181	192	196	198	198	193	192	187	180
1917	201	197	190	199	197	198	210	212	206	201	196	162	197
1918	146	173	170	146	200	210	212	210	207	201	199	198	189
1919	185	184	191	194	199	196	199	195	193	192	186	177	191
1920	147	153	182	189	195	191	196	197	196	191	186	186	184
1921	189	132	145	183	190	186	188	186	182	182	175	177	176
1922	166	140	175	185	182	186	191	191	190	182	180	178	179
1923	150	156	165	173	176	179	183	182	182	179	173	170	172
1924	165	126	147	165	171	173	175	180	180	173	172	167	166
1925	133	136	156	161	162	165	167	164	161	160	156	155	156
1926	120	106	134	156	158	164	165	164	162	158	158	157	150
1927	122	116	152	165	171	175	178	178	175	177	174	165	162
1928	162	140	140	181	186	186	190	193	196	199	201	197	181
1929	174	168	150	202	209	214	218	218	214	209	206	186	197
1930	164	161	189	186	189	194	201	202	197	193	186	181	187
1931	134	107	118	167	174	174	174	170	167	167	167	162	157
1932	156	157	126	161	160	162	164	164	163	162	157	142	156
1933	145	120	141	144	157	166	167	160	158	154	153	151	151
1934	111	124	122	150	158	156	157	159	159	161	160	162	148
1935	132	117	159	168	170	170	171	170	168	168	168	149	159
1936	125	144	146	161	164	168	167	170	173	171	166	161	160
1937	157	125	160	158	163	163	161	161	160	160	162	150	157
1938	124	142	124	164	168	174	176	178	177	180	178	169	163
1939	155	104	134	169	176	180	182	182	184	181	179	173	167
1940	124	126	141	164	168	170	172	175	176	173	173	169	161
1941	133	115	149	163	175	175	172	170	169	174	174	175	162
1942	165	99	155	182	182	188	189	186	186	184	180	177	173
1943	118	133	172	185	181	194	210	213	209	207	204	196	185
1944	145	162	169	195	197	197	201	200	199	200	194	182	187
1945	150	161	186	188	195	200	202	200	200	198	195	177	188
1946	170	143	192	201	199	199	200	200	195	191	191	188	181
1947	154	143	182	188	190	194	202	204	202	200	198	195	188
1948	168	164	189	196	202	198	198	198	192	182	177	180	187
1949	181	177	150	179	179	179	180	180	176	172	169	166	174
1950	162	138	149	171	173	176	185	187	189	189	187	185	174
1951	169	170	185	194	201	205	211	213	213	216	218	204	200
1952	200	205	208	218	221	225	228	231	230	223	216	216	218
1953	213	205	207	212	213	218	222	223	220	215	209	204	213
1954	170	154	202	203	207	212	218	217	215	222	217	214	204
1955	201	188	202	206	208	212	210	208	199	193	189	186	200
1956	122	120	170	188	194	194	196	198	194	190	187	183	178

TABLE 11–67 Total Monthly Mean Diversion to Lake Superior Basin from Albany River Basin through Ogoki and Long Lake Projects in Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1939	----	----	----	----	----	----	105	365	369	190	0	0	----
1940	0	0	0	0	578	847	1122	1281	881	0	0	0	392
1941	212	723	612	668	1489	1621	1402	1216	1288	1205	1737	1550	1144
1942	1235	939	725	724	1780	2307	1927	1607	1270	550	2092	1876	1419
1943	1466	1143	866	705	1607	2281	3152	4209	5053	5468	5316	4530	2983
1944	3978	3384	2663	2439	4663	8026	7362	2962	2317	3837	2816	2563	3918
1945	2882	2052	1937	2574	3608	7113	8696	6388	3767	3733	3980	3697	4202
1946	3312	2872	2785	3777	10061	12484	10627	5652	3807	4671	7351	7287	6224
1947	5075	3990	2950	2425	7635	8500	9845	5180	4950	4035	3390	3720	5141
1948	3550	2835	2165	2560	8200	9315	9075	7590	4565	3335	3330	4700	5102
1949	3705	3435	3515	4855	10266	10430	5435	4745	3610	3645	4595	4940	5265
1950	5025	4420	3875	3470	8930	2290	2315	2115	6984	3550	6845	6655	4706
1951	4755	3725	3065	2550	4645	2970	3575	4700	3980	7575	7540	9440	4877
1952	6320	4880	3773	1945	985	2095	2040	1540	1270	1245	880	3420	2533
1953	6125	3870	3185	3220	5355	9305	9305	1250	1350	3215	7925	5240	4945
1954	7490	5605	4395	3890	7460	2585	1270	5985	5920	5940	6395	7560	5375
1955	5102	4505	3990	4086	9723	10686	9762	5611	4265	3795	4419	4678	5900
1956	4328	3892	3468	3263	4769	14565	11344	6935	4807	4411	4374	4630	5899
1957	3804	3130	2865	3242	9424	10921	2645	6617	4423	4218	5489	4542	5110
1958	3887	3828	3548	3817	8897	11370	8237	5876	5356	7203	8677	6865	6463
1959	5597	4951	3804	3602	5142	12181	12796	9148	6694	6143	5226	4774	6672
1960	4057	3960	3288	3218	5895	9879	7722	4866	3507	2722	3503	3894	4709
1961	3844	3697	3419	3493	9411	13165	7825	4887	3510	4010	4720	4090	5506
1962	3960	4040	3450	3210	4790	10250	8650	7780	7960	5910	4570	3960	5711
1963	3880	3590	3090	3190	4340	8310	7040	9890	9090	5930	4200	3710	5522
1964	3580	3400	3100	3430	11160	12780	7330	12120	10620	12670	9350	6630	8014
1965	5360	4550	4810	4750	6600	8400	7450	6150	4770	7020	7650	7310	6235
1966	6580	5610	4700	4620	8380	17680	5000	10230	6490	4700	4010	3540	6795
1967	3720	3310	2910	3370	6420	13490	9650	6230	3925	3032	3510	3550	5260
1968	3730	3260	2950	3900	9900	15790	9760	3860	3350	2910	12570	8920	6741
1969	6470	5600	4590	4400	10410	16310	5260	1380	12300	8800	6589	5447	7296
1970	4800	4470	3800	3260	6280	9890	11170	8830	8760	12300	3010	6190	6897

TABLE 11-68 Monthly Mean Diversion to Lake Superior Basin from Albany River Basin through Ogoki Project in Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1943	----	----	----	----	----	----	723	2122	3197	4047	4026	3400	----
1944	3048	2650	2048	1865	2626	5298	5186	460	0	2187	1211	1184	2314
1945	1795	1200	1244	1258	2514	4930	6647	4723	3131	2654	2682	2579	2946
1946	2409	2153	2199	2815	7462	9784	8004	3808	2420	3562	5661	5497	4648
1947	3785	2885	2235	1830	6165	6305	7605	3165	3375	2920	2590	2590	3787
1948	2690	2180	1865	2335	7115	7690	7670	6705	3865	3065	3265	3720	4347
1949	2855	2195	1905	3355	9110	8315	4355	3975	2590	2585	3270	3515	4002
1950	3430	2820	2475	2415	7065	0	0	735	5650	2105	4410	4465	2964
1951	3200	2510	2130	1660	2705	1370	2270	3700	3030	6410	6050	7785	3568
1952	4710	3435	2745	1230	15	0	0	0	0	0	0	2560	1225
1953	5195	2830	2250	2290	3500	7090	7060	160	160	1950	6795	4265	3629
1954	6350	4290	3210	2895	4765	0	150	4810	4725	5035	5215	6490	3994
1955	3962	3010	2565	3225	7760	9135	8450	4488	2992	2814	3401	3634	4620
1956	3344	3024	2555	2465	4179	12388	9755	5770	3751	3081	3156	3690	4763
1957	3056	2442	2172	2426	6909	8289	718	5355	3209	2957	4257	3355	3762
1958	2419	2328	2364	2632	6477	8476	6065	4581	3991	6039	7278	5834	4874
1959	4253	3218	2546	2617	3961	10309	11606	8083	5865	5348	4420	3939	5514
1960	3072	2592	2200	2296	4108	7360	6313	3916	2621	2063	2269	2446	3438
1961	2366	2060	2042	2277	6798	10921	6519	4028	3029	2490	2760	2910	4017
1962	2550	2120	2010	1960	3330	7480	7550	6610	6140	4550	3290	2660	4188
1963	2470	2200	2020	2260	3180	5540	5980	8910	7960	4710	3040	2500	4231
1964	2340	2220	2030	2200	8070	9310	4570	10030	8830	10050	7640	5110	6033
1965	3870	3130	2770	2580	4140	6290	6370	5170	4070	4830	6270	5840	4611
1966	4750	3890	3380	3280	5550	14990	3300	7990	4690	3070	2390	2020	4942
1967	1720	1590	1680	1910	3310	10570	7900	4720	3220	2290	2110	1850	3573
1968	1800	1690	1780	2440	7230	12970	6870	1330	2150	1540	11010	7070	4823
1969	4690	3900	3190	3040	7460	13300	3520	0	11030	7620	5690	4640	5673
1970	3580	2880	2440	2210	4250	6850	8610	7420	7500	9940	710	4550	5078

TABLE 11–69 Monthly Mean Diversion to Lake Superior Basin from Albany River Basin through Long Lake Project in Cubic Feet per Second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1939	----	----	----	----	----	----	105	365	369	190	0	0	----
1940	0	0	0	0	478	847	1122	1281	881	0	0	0	392
1941	212	723	612	668	1489	1621	1402	1216	1288	1205	1737	1550	1144
1942	1235	939	725	724	1780	2307	1927	1607	1270	550	2092	1876	1419
1943	1466	1143	866	705	1607	2281	2429	2087	1856	1421	1290	1130	1524
1944	930	734	615	574	2037	2728	2176	2502	2317	1650	1605	1379	1604
1945	1087	852	693	1316	1094	2183	2049	1665	636	1079	1298	1118	1256
1946	903	719	586	962	2599	2700	2623	1844	1387	1109	1690	1790	1576
1947	1290	1105	715	595	1470	2195	2240	2015	1575	1115	800	1130	1354
1948	860	655	300	225	1085	1625	1405	885	700	270	65	980	755
1949	850	1240	1610	1500	1156	2115	1080	770	1020	1060	1325	1425	1263
1950	1595	1600	1400	1055	1865	2290	2315	1380	1334	1445	2435	2190	1742
1951	1555	1215	935	890	1940	1600	1305	1000	950	1165	1490	1655	1308
1952	1610	1445	1028	715	970	2095	2040	1540	1270	1245	880	860	1308
1953	930	1040	935	930	1855	2215	2245	1090	1190	1265	1130	975	1317
1954	1140	1315	1185	995	2695	2585	1120	1175	1195	905	1180	1070	1380
1955	1140	1495	1425	861	1963	1733	1310	1123	1273	981	1018	1044	1281
1956	984	868	913	798	590	2177	1589	1165	1056	1330	1218	940	1136
1957	748	688	693	816	2515	2632	1927	1262	1214	1261	1232	1187	1348
1958	1468	1500	1184	1185	2420	2894	2172	1295	1365	1164	1399	1031	1590
1959	1344	1733	1258	985	1181	1872	1190	1065	829	795	806	835	1158
1960	985	1368	1088	922	1787	2519	1409	950	886	659	1234	1448	1271
1961	1478	1637	1377	1216	2613	2244	1306	859	481	1520	1960	1180	1489
1962	1410	1920	1440	1250	1460	2770	1100	1170	1820	1360	1280	1300	1523
1963	1410	1390	1070	930	1160	2770	1060	980	1130	1220	1160	1210	1291
1964	1240	1180	1070	1230	3090	3470	2760	2090	1790	2620	1710	1520	1981
1965	1490	1420	2040	2170	2460	2110	1080	980	700	2190	1380	1470	1624
1966	1830	1720	1320	1340	2830	2690	1700	2240	1800	1630	1620	1520	1853
1967	2000	1720	1230	1460	3110	2920	1750	1510	705	742	1400	1700	1637
1968	1930	1570	1170	1460	2670	2820	2890	2530	1200	1370	1560	1850	1918
1969	1780	1700	1400	1360	2950	3010	1740	1380	1270	1180	899	807	1623
1970	1220	1590	1360	1050	2030	3040	2560	1410	1260	2360	2300	1640	1818

TABLE 11-70 Monthly and Annual Mean Outflow from Lake Michigan Basin through the Chicago Sanitary and Ship Canal in Cubic Feet per Second (Consisting of Diversion from Lake Michigan Watershed and Domestic Pumpage)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1955	2731	2809	2626	3525	3708	3706	3661	3797	3261	2825	2821	3455	3244
1956	2830	2790	2725	3507	3439	3586	3848	4052	3260	3242	2882	5834	3499
1957	9102[c]	8009[c]	2863	3357	3352	3355	4015	3427	2998	3146	3045	3379	4171
1958	2877	3341	2785	3245	3419	3500	3640	3456	3125	2962	3341	3409	3258
1959	4626	2592	2814	2840	2670	3357	3699	4164	3242	3069	2937	3478	3291
1960	3571	2905	3060	3660	3457	3256	3217	3187	3400	2933	3021	3580	3271
1961	2915	2906	3013	3530	3540	3711	3671	3731	4551	2292	2035	2968	3239
1962	2944	2442	2538	2916	3547	3668	3834	4079	3707	3131	3127	3527	3288
1963	2413	2662	2758	3892	3929	3758	3832	3565	3212	2729	3117	3399	3272
1964	2488	2473	2679	3222	3502	3944	4098	3651	3712	2747	3483	3142	3262
1965	2841	2789	3018	3367	2967	3181	3433	4225	3642	2788	2780	3390	3202
1966	2275	2638	2880	3436	4058	2620	3354	3973	3482	2740	3308	3642	3200
1967	2296	2426	2810	3553	2568	3940	3235	3703	3914	4008	3025	3387	3239
1968	2233	2478	1803	2767	3307	3726	3658	4341	3415	3294	3879	4445	3279
1969	2894	2026	2180	3551	3644	4444	4871	4267	4051	3116	1951	1943	3245
1970	2865	3243	2215	4320	4545	4286	3669	3251	3595	3106	2684	2211	3333

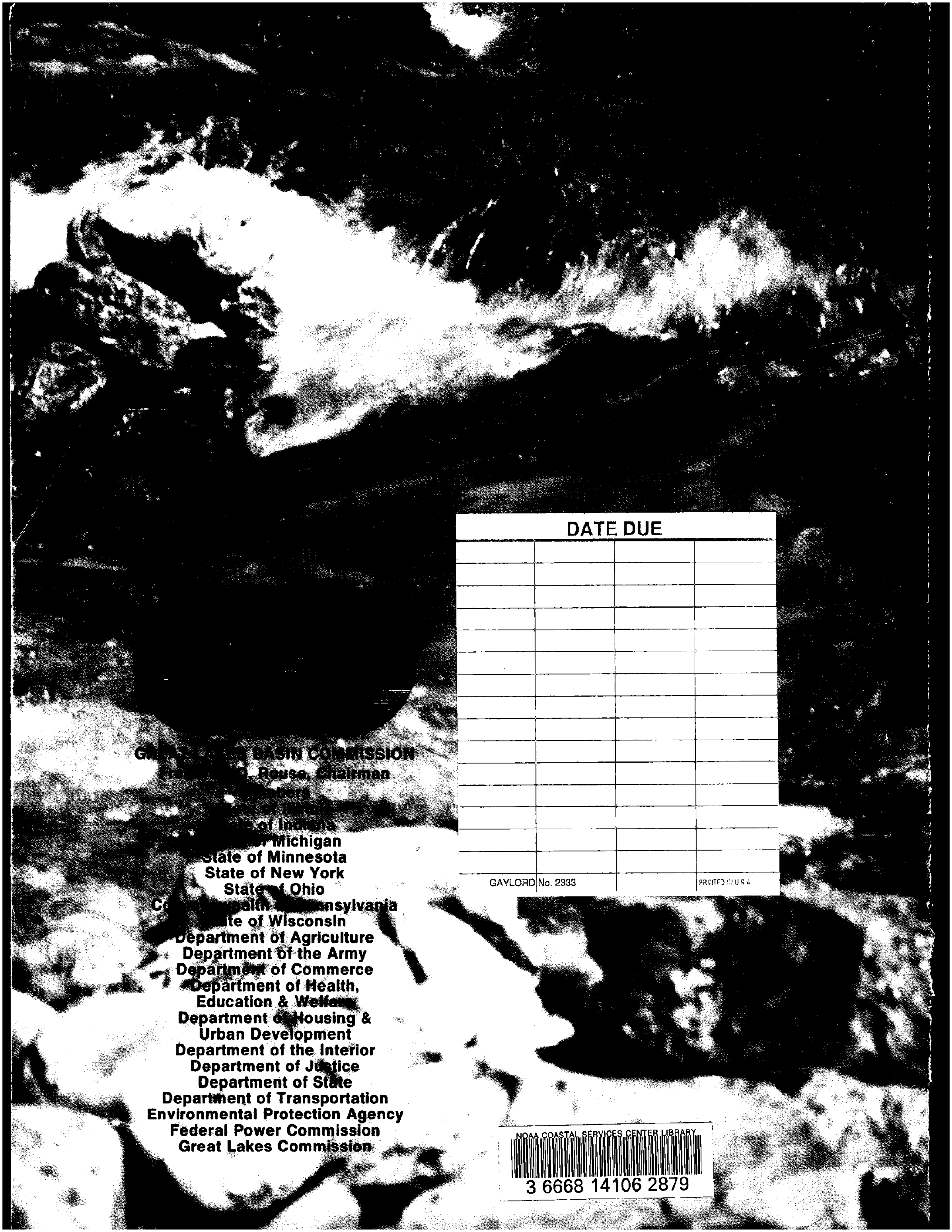
[a] as reported by Sanitary District of Chicago

[b] The U.S. Supreme Court on December 17, 1956 authorized an increase in diversion from Lake Michigan Watershed from 1500 cfs to an amount not exceeding an average of 8500 cfs in addition to Domestic Pumpage to and including January 31, 1957 and on January 28, 1957 extended this authorized increase to and including February 28, 1957.

TABLE 11-71 Annual Mean Outflow from Lake Michigan Basin through Illinois and Michigan Canal in Cubic Feet per Second

Period	Outflow
1860-1864	100
1865-1870	200
1871-1883	300
1884-1886	1,000
1887-1888	900
1889	800
1890	700
1891-1894	600
1895-1897	500
1898-1903	600
1904-1910	700

NOTE: This diversion ceased upon completion of the Chicago Sanitary and Ship Canal in 1910.



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